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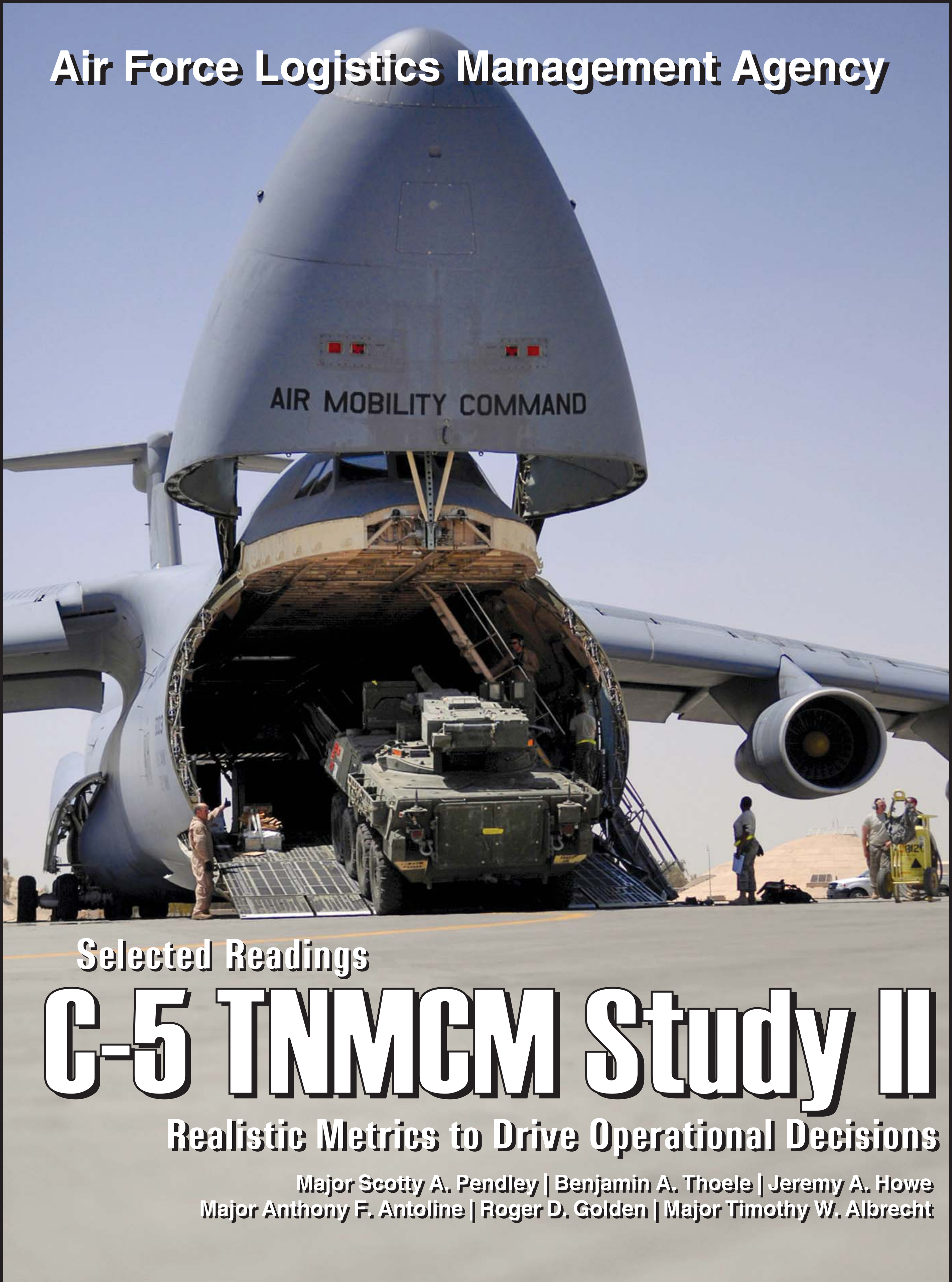

Selected Readings

C-5 TNMCM Study II

Realistic Metrics to Drive Operational Decisions

Major Scotty A. Pendley | Benjamin A. Thoele | Jeremy A. Howe
Major Anthony F. Antoline | Roger D. Golden | Major Timothy W. Albrecht

C-5 TNMCM Study II

Realistic Metrics to Drive Operational Decisions

The Editors, Air Force Journal of Logistics

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Major Anthony F. Antoline, PhD, Contributing Editor

Air Force Logistics Management Agency
501 Ward Street
Maxwell AFB, Gunter Annex, Alabama 36114-3236

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Foreword

C-5 TNMCM Study II

The C-5 TNNCM Study II proved to be a stern test of AFLMA's abilities and perseverance. Considering the numerous potential factors which impact TNMCM rates as well as the C-5s historical challenges in the areas of availability and achieving established performance standards, the study team was determined to apply new thinking to an old problem. The research addressed areas of concern including maintaining a historically challenged aircraft, fleet restructuring, shrinking resources, and the need for accurate and useful metrics to drive desired enterprise results.

The team applied fresh perspectives, ideas and transformational thinking. As a result, the study team developed a new detailed methodology to attack similar research problems, formulated a new personnel capacity equation that goes beyond the traditional *authorized versus assigned* method, and analyzed the overall process of setting maintenance metric standards. AFLMA also formed a strategic partnership with the Office of Aerospace Studies at Kirtland AFB in order to accomplish an analysis of the return on investment of previous C-5 modifications and improvement initiatives. A series of articles was produced which describes various portions of the research and accompanying results. Those articles are consolidated in this book.

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C-5 TNMCM Study II

Realistic Metrics to Drive Operational Decisions

Major Scotty A. Pendley, AFLMA

In order to blueprint an exportable methodology, the study team developed and utilized the Hierarchical Holographic Model and a ranking and filtering process. This overall process is suitable for complex problem modeling and is exportable to other weapon systems.

Introduction

Aircraft maintenance has been and continues to be a challenging, complex task involving a delicate balance of resources to include personnel, equipment, and facilities. Adding to this challenge is the fact that the balancing act occurs in a very hectic environment where the United States Air Force flies 430 sorties per day in support of Operations Iraqi Freedom and Enduring Freedom. And somewhere in the world, a mobility aircraft takes off approximately every 90 seconds.[1] At the same time, the number of airmen supporting our aircraft is declining. "Since 2001 the active duty Air Force has reduced its end-strength by almost 6 percent but our deployments have increased by at least 30 percent, primarily in support of the Global War on Terror."[2] This reduction in personnel is part of the Air Force process of drawing down the total force by approximately 40,000 people, with many of these cuts in aircraft maintenance career fields. Also adding to the growing maintenance workload is an aircraft fleet which now averages almost 24 years old, with the average still increasing.[3]

Background

When it comes to aircraft maintenance, the Air Force depends on metrics to gauge whether or not we are measuring up to the standard and succeeding in our maintenance efforts. One of the most recognized metrics is the total not mission capable maintenance (TNMCM) rate. Air Force Instruction (AFI) 21-101 describes TNMCM as "perhaps the most common and useful metric for determining if maintenance is being performed quickly and accurately."[4] Although a lagging type indicator, it is one of several key metrics followed closely at multiple levels of the Air Force. Over the last few years, the Air Force TNMCM rate increased across many platforms. TNMCM discussions by Air Force leadership ultimately resulted in the Air Force Materiel Command Director of Logistics (AFMC/A4) requesting the C-5 TNMCM Study II (AFLMA) to conduct an analysis of TNMCM performance with the C-5 Galaxy aircraft as the focus. AFLMA was commissioned to conduct an analysis of C-5 TNMCM performance to identify root causes, indicators, and potential corrective actions to bring TNMCM within standard, the intent being to export the methodology and any lessons learned to other weapon systems.

Considering the numerous potential factors which impact TNMCM rates, as well as the C-5's historical challenges in the areas of availability and achieving established performance standards, it was obvious that this project's scope was broad, and a smart way to eat such a *big elephant* was needed. Our team just had to figure out a way to consume the beast one piece at a time and not become overwhelmed during the process. AFLMA eventually conducted two studies in support of the original study request. This article and succeeding articles focuses on the second of those studies, the C-5 TNMCM Study II, and the methodology used to accomplish this daunting task.

Problem Statement

The Air Force C-5 fleet TNMCM rate steadily increased from 25 percent to 38 percent from 2004 to 2006. In addition, the current methodology for establishing aircraft metric standards is insufficient at communicating the overall health of the fleet. Finally, a better understanding of the return on investment (ROI) of previous improvement initiatives will enable leadership to more efficiently direct resources.

The study included five overall objectives:

- Identify root causes and indicators of increasing C-5 TNMCM rates
- Identify potential corrective actions necessary to bring the C-5 TNMCM rate within standards
- Develop a standardized analytical approach which is exportable to other Air Force aircraft
- Analyze the process for calculating and establishing aircraft TNMCM standards
- Review historical C-5 modifications and reliability initiatives for ROI

The scope of this research was limited to the various models within the C-5 fleet and no other mission design series (MDS). The scope included previous work related to Air Force aircraft maintenance, historical aircraft modifications, metrics and factors which potentially impact those metrics, and previous and ongoing C-5 issues and challenges. The study team also examined commercial aviation maintenance practices and metrics for applicability. The bulk of the research focused on disaggregated data and analysis, that is, comparisons between C-5 aircraft models and between the total force component (active duty, Guard, or Reserve) in order to examine potential root causes in greater detail.

Research and Analysis

This project involved two main phases: data collection and data analysis. The data collection phase involved a thorough review of existing literature and resources related to aircraft maintenance, particularly C-5 aircraft, and also literature which could assist with scoping and organizing a project of this magnitude. In addition, current commercial aircraft maintenance philosophy and practices were examined as well as applicable Department of Defense (DoD) and Air Force regulations and instructions.

The data collection phase included numerous discussions with C-5 aircraft program managers and aircraft maintenance subject matter experts (SME). Points of contact were established from various phases of the C-5 support, sustainment, and policy arenas including representatives from Air Mobility Command (AMC), Air Force Materiel Command (AFMC), the C-5 Depot at Warner Robins Air Logistics Center (WR-ALC), and Headquarters (HQ) Air Force Air Staff. In addition, personnel from the RAND Corporation and the Logistics Management Institute (LMI) were consulted.

The project's first phase also included preliminary analysis of data from the system of record, the Reliability and Maintainability Information System (REMIS), as well as some basic trending and historical data from the Multi-Echelon Resource and Logistics Information Network (MERLIN) database. In conjunction with this preliminary analysis, our team conducted site visits at the C-5 Aircraft Sustainment Group at Wright-Patterson Air Force Base (AFB), C-5 Sustainment Wing and Depot facilities at Robins AFB, Westover Air Reserve Base (ARB), Dover AFB, and Stewart Air National Guard Base (ANGB). These site visits were invaluable in understanding C-5 maintenance and data collection processes across the total force, the complexity of the airframe itself, facilities and equipment, ongoing modernization efforts, and the day-to-day processes required to maintain the C-5.

Question sets were developed for each of the different areas of a maintenance complex to include the squadrons and flights within a typical maintenance group (MXG). These question sets were utilized to gather data during the site visits and were refined as the project continued in an effort to develop a standardized questioning protocol which was repeatable and could be exportable for use with similar research in the future.

TNMCM Root Causes and Indicators

To visualize the complexity and interaction of all potential factors affecting C-5 TNMCM time, the study team employed a tool from the field of risk analysis, a Hierarchical Holographic Model (HHM).[5] HHM is an established risk analysis methodology developed by Dr Yacov Y. Haimes at the University of Virginia. Dr Haimes has completed several studies for the DoD, such as risk analysis of military operations other than war[6] and the probability of land mine contamination.[7] Haimes also used HHM in work for National Aeronautics and Space Administration (NASA) to determine the various risk scenarios affecting space shuttle missions.[8]

The HHM provided a framework for considering multiple decompositions (perspectives or views) of the system. Overall, each major view in an HHM represents a high-level factor, in this case factors contributing to not mission capable maintenance (NMCM) hours, and these high-level factors are decomposed into submodels. The HHM also enables both a systematic and systemic framework for the problem and each submodel can be analyzed independently as well as in relationship to other submodels, with analysis of an entire HHM providing a coordinated solution to the problem. With the tools just mentioned and initial data from numerous sources, the study moved into the data analysis phase.

Preliminary analysis resulted in an initial HHM with 184 factors that potentially contribute to the C-5 TNMCM rate. The HHM went through several iterations before it was considered complete. The final iteration of the HHM is shown in Figure 1. The 12 high-level factors are listed horizontally across the top with submodels for each high-level factor located vertically underneath. In order to scope the project to a manageable number of factors to analyze further, and focus the remaining research on factors with the most potential to result in decision-quality results, our team developed a ranking and filtering process. This process considered each factor according to three criteria (factor weights in parenthesis):

- Impact on maintenance time (0.53)
- Data availability (0.30)
- Previously published research on the factor (0.17)

The three criteria were also scored using an ordinal scale with high = 1.0, medium = 0.5, and low = 0.0.

Table 1 describes the rule set observed when scoring the factors. The calculated total score for each factor was the result of the linear decision model; that is, the total score was equal to the sum product of the criteria weights and the criteria scores. The result was a normalized score on the interval [0, 1] for each factor. This score could then be used to perform an ordinal ranking of all 184 factors according to the criteria. The factors were sorted by total score, then alphabetically by category and subcategory. It is important to note that factors with little previous research actually received higher scores. This was part of an effort by the study team to go beyond the existing body of work and factors previously or currently considered on a regular basis.

Using this iterative process, the original 184 initial factors were scaled down to 25 high-level factors. In most cases, continuing analysis of the 25 high-level factors revealed limitations to either data availability, quantifiable impact, or both. Two factors ultimately stood out as the most fruitful to produce actionable, decision-quality results. These factors were

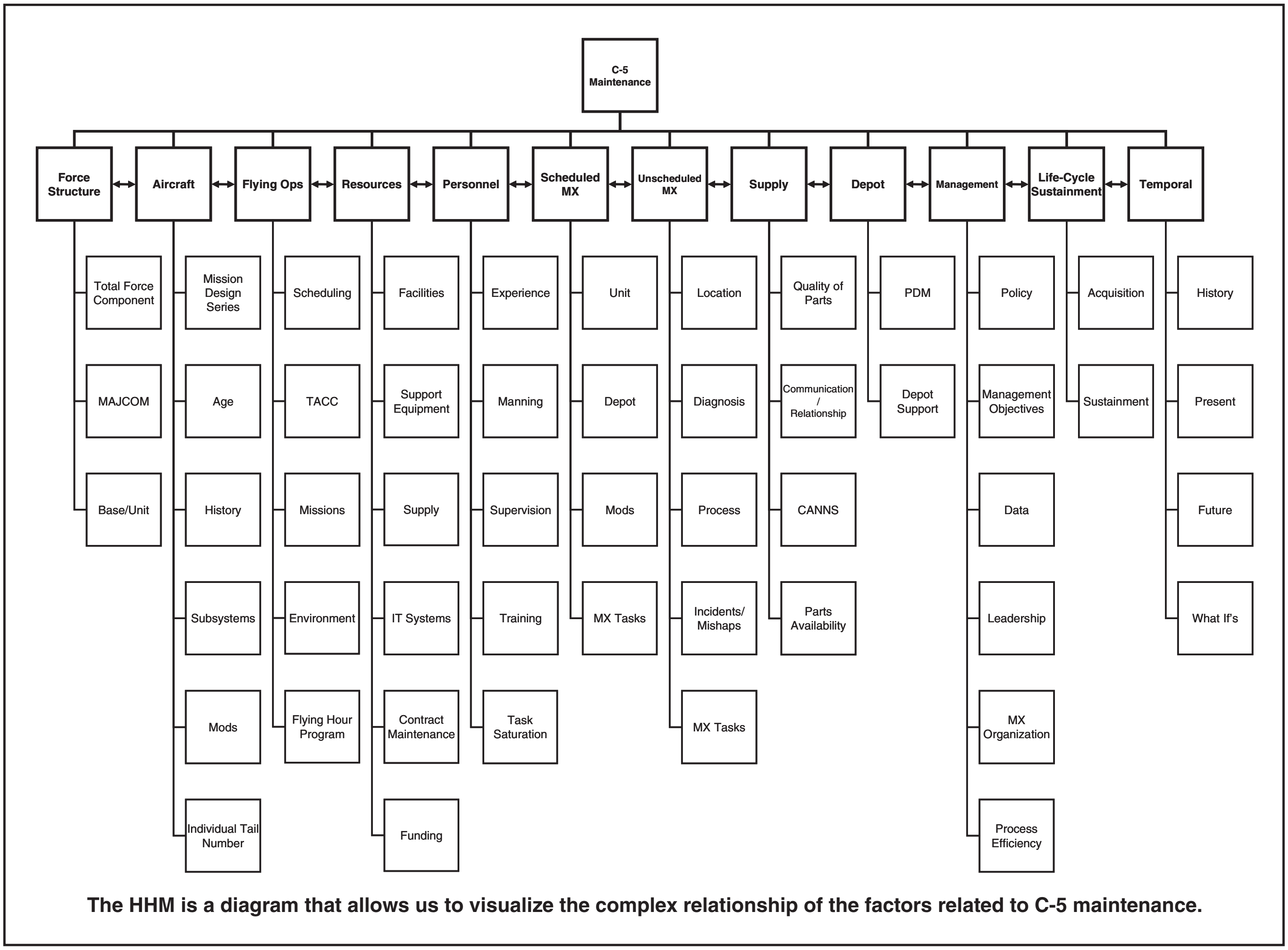

Figure 1. Hierarchical Holographic Model for the C-5 Maintenance System

		Scores		
		1.0	0.5	0.0
Criteria	Impact to NMCM Time and TNMCM Rate	Direct impact; clear relationship witnessed from preliminary studies; or something so obvious that it should not be ignored.	Indirect impact; or intuitive relationship, but not sure exactly how.	Minimal impact; only related in an “Everything is connected in the universe” way.
	Data Availability	Data exists in a single source; source recognized as the original source; minimal effort to draw fact-based conclusions.	Data exists in multiple unrelated sources; extensive mining and data reduction required; or data exists for recent FYs only.	No data known to exist; would have to conduct an acute data collection effort to draw any fact-based conclusions.
	Previous Work or Studies	Fairly new idea; cutting edge of C-5 and/or general aircraft maintenance body of knowledge.	1-2 major studies; no actions taken or decisions have been made to address the factor.	2 or more major studies; actions have been taken or decisions have been made to address the factor.

Table 1. Factor Subjective Scoring Rationale

$$NEP = T_{75}(A_{75NT} + (P_t A_{75T})) + T_3(P_e A_3)$$

Equation 1. Net Effective Personnel

Factor	Description	Value
T_{75}	Ancillary/CBT Factor for 7- and 5-levels	0.948
A_{75NT}	The number of available nonmanager 7-levels and 5-levels who are not trainers	Varies day-to-day
P_t	Trainer Productivity	0.85
A_{75T}	The number of available nonmanager 7-levels and 5-levels who are trainers	Varies day-to-day
T_3	Ancillary/CBT Factor for 3-levels	0.925
P_e	Trainee Productivity	0.4
A_3	The number of available 3-levels	Varies day-to-day

Table 2. NEP Factors

aligning personnel capacity with demand and the logistics departure reliability (LDR) versus TNMCM metrics paradigm.

Aligning Personnel Capacity with Demand

One measure historically used to quantify personnel availability is the ratio between authorized and assigned personnel. While this ratio is an indicator of maintenance capacity, it provides only a limited amount of information. Authorized versus assigned ratios do not take into account the abilities and skill levels of the maintenance personnel, nor does it factor in the availability of the personnel on a day-to-day basis. These issues were addressed in the C-5 TNMCM Study II by quantifying "we need more people," beyond the traditional metric of authorized versus assigned personnel.

To further analyze this factor, our team developed a new personnel capacity equation which encompassed three factors which impact variability in the maintenance technician pool.

- Personnel availability
- Skill-level productivity
- Ancillary and computer-based training (CBT) requirements

The influence of these three factors and their impact on the viable resource pool for the 436 MXG at Dover AFB was examined over a 9-week period during March-April 2007. This collective impact yielded a new resource pool representing a depiction of *effective* capacity rather than just the authorized versus assigned ratio. This new resource pool was denoted as Net Effective Personnel, or NEP, and is detailed in Equation 1. The newly designated factors, factor descriptions, and the associated values used in the NEP equation are listed in Table 2.

The *T* factors relate to training, the *A* factors relate to available personnel, and the *P* factors relate to productivity. These factors were applied to the number of available technicians as recorded in the Dover Aircraft Maintenance Squadron availability snapshots using the newly proposed NEP calculation.

The resulting Dover AFB NEP results and the calculated demand at Dover, defined as aircraft launches and recoveries, were compared using averages for both values over each weekday. This resulted in a comparison of the ratio of NEP per demand event. From this, we demonstrated a current suboptimization of personnel distribution over an average week. Therefore, the study team proposed a realignment of maintenance personnel capacity to better utilize available personnel. This resulted in an estimated improvement (reduction) in the TNMCM rate of 0.040, or approximately 4 percentage points. This assumed the data set utilized represented typical demand.

LDR versus TNMCM Metrics Paradigm

The second factor for detailed focus was the LDR versus TNMCM metric comparison. Based on site visits and feedback from MXG senior leaders and all but one C-5 MXG commander (MXG/CC), the study team determined that the primary metric of the MXG/CC was LDR and that aircraft availability, which is directly related to the TNMCM rate, was the primary metric of higher level leadership. While not totally unexpected, the focus of different levels of an organization on different metrics can be problematic for the enterprise when the pursuit of goals at the local level may not be complimentary to goals at the strategic level. If the metrics are not aligned, pursuit of better performance in a lower level metric could result in worse performance for higher level metrics.

To analyze the potential effects of misaligned metrics, the study team utilized a definition of aligned metrics, which stated that a set of metrics is aligned if improvement in the lower level metric implies improvement of the higher level metric. In order to test the theoretical effect of improving home station LDR (HSLDR) on TNMCM rates, the study team constructed a discrete event simulation using Arena software. The simulation allowed the team to study how different maintenance operations could affect the HSLDR and TNMCM rates in a controlled environment, something impossible to do in the real world. The simulation used Dover AFB aircraft arrival and maintenance-related data from January 2006 through March 2007 to examine the impact of four different priority policies for a hypothetical aircraft maintenance queue. These policies were

- Least maintenance – priority given to an aircraft that requires the least man-hours to make it mission capable (MC)
- Most maintenance – priority to aircraft with the most man-hours of repair remaining
- First-in-first-out (FIFO)
- Last-in-first-out (LIFO)

The simulation confirmed that LDR and TNMCM react differently depending on the prioritization policy. The simulation also demonstrated that changing prioritization policies can improve TNMCM but at a cost to predictability and

LDR, depending on the scenario. Overall, the simulation results supported the idea that the priorities of the maintainers impact the metrics and suggest that current maintenance policies do not ensure TNMCM improvement, but do improve LDR.

TNMCM Standard

Another study objective was to analyze the process for calculating and establishing aircraft TNMCM standards. The 2003 CORONA directed that Air Force-wide standards for MC, TNMCM, and total not mission capable supply (TNMCS) be established. While directed toward TNMCM, this research revealed that the MC standard is the foundation for calculating the other two metrics' standards. As the process currently exists, the Air Force MC standards are based on requirements and those requirements are determined in one of three ways:

- The flying hour or flying schedule requirement,
- A contract logistics support (CLS) contract, or
- Another requirement based on major command (MAJCOM) input with those inputs determined by the designed operational capability (DOC) statement, readiness study, or any operational requirement the MAJCOM may use

This is not the case for the separate Air Force Reserve Command (AFRC) and Air National Guard (ANG) fleet C-5 MC standards. Those two values are calculated at the Air Staff level. The AFRC MC standard is calculated from utilization rate, attrition, turn pattern, annual fly days, spares, aircraft held down for scheduled maintenance, and primary aerospace vehicle (aircraft) authorized (PAA). The ANG MC standard equation uses variables portraying daily operations and maintenance (O&M) flying hours, aircraft taskings per flying day over and above O&M flying, average number of aircraft required for standard flying operations each day, required daily spares, and the forecast number of unit possessed aircraft over the year.

In the case of the C-5, AMC provides the active duty fleet MC standard to the Air Staff and this standard is based on the Mobility Requirements Study (MRS). However, it is not actually calculated in the MRS, it is an assumption used in the MRS. The director of the AMC Office of Analysis, Assessments, and Lessons Learned (AMC/A9) concurred that the C-5 MC standard is not based on any formal calculation or analysis, and stated that the original estimate (circa 1990) of a 75 percent MC rate was deemed a *prudent objective* for planning purposes.[9]

During Operations Desert Shield and Desert Storm in fiscal year 1991, the C-5 fleet MC rate achieved was less than 71 percent. During Operation Iraqi Freedom in FY 03, the C-5 fleet MC rate was less than 64 percent. This is particularly intriguing because numerous personnel interviewed suggested that MC rates are usually better during conflicts. Indeed, the highest quarterly MC rate the C-5 fleet has ever achieved, 81.8 percent, was observed during FY 91, Quarter 1 (Operation Desert Shield). These observations bring into question the feasibility of a 75 percent figure for use as a realistic peacetime standard. Still, consistent failures to meet a standard are more than likely perceived as a shortfall in the performance of the units supporting the C-5, rather than an unrealistic expectation not being met. A tremendous amount of time and effort is put forth explaining why standards are not met. Historical performance would suggest that the standard is not driving improvement in performance, which is the fundamental purpose of a performance measure. It should drive performance, not simply document it, and the measure should be useful for decisionmaking.

The examination of the standards calculation methodology suggests that the C-5 MC, TNMCM, and TNMCS standards fall short in the areas of accuracy, objectivity, and ease. AFI 21-101 states that "metrics shall be used at all levels of command to drive improved performance."[10]

At least in the case of the C-5, the existing maintenance standards referenced here and their associated metrics appear to fall short of this goal.

Historical Modifications and Improvement Initiatives Return on Investment

At the beginning of this article a reference was made to how our study team needed to eat the entire elephant smartly, the elephant being the C-5 TNMCM Study II. Our team realized very early that a research partner would be needed in order to accomplish all the study's objectives in the given time frame. AFLMA formed a strategic partnership with the Office of Aerospace Studies (OAS) at Kirtland AFB in order to accomplish the return on investment objective of the study. The OAS research team consisting of Captain Greg Steeger and First Lieutenant Matt Compton pursued three questions asked by the project sponsor:

- What was the C-5 advertised reliability *out of the box*
- What modifications were completed on the aircraft
- What was the ROI from these modifications

OAS developed the ROI methodology, data requirements, and the overall research process for this particular study objective. OAS used the Air Force Smart Operations for the 21st Century (AFSO21) definition for ROI in conjunction with a formula which utilized the maintenance man-hours (MMH) saved from completing a modification in the year after the modification was completed. The MMH savings were then multiplied by the cost per MMH and that resulting number was then divided by the total modification cost to ultimately calculate the ROI for a particular C-5 modification.

OAS also conducted an exhaustive literature review of their own and analyzed the C-5 time compliance technical order (TCTO) database scouring literally thousands of TCTOs, in addition to a site visit to Warner Robins Air Logistics Center in pursuit of all potential data sources and subject matter expertise which might assist in that phase of the research. Still, OAS research was limited by a lack of data. Detailed historical data on many past C-5 modifications either did not exist or could not be located. Much of the data required for their objective of the study was apparently lost when the C-5 depot responsibilities transferred from Kelly AFB to Robins AFB. Regardless, OAS developed a sound methodology for analyzing potential ROI for aircraft modifications. OAS wrote their portion of the study's report as a stand alone document and it was included in the overall final study report as Appendix F.

Conclusions

In order to blueprint an exportable methodology, the study team developed and utilized the HHM and a ranking and filtering process. This overall process is suitable for complex problem modeling and is exportable to other weapon systems.

The exhaustive analysis resulted in the study team scaling down from 184 potential C-5 TNMCM root causes to two factors yielding actionable, decision-quality results. These factors were aligning personnel capacity with demand and the LDR versus TNMCM metrics paradigm.

The process for calculating and establishing Air Force level TNMCM standards is not well known across the Air Force and not equally applied across the total force. Also, the process currently in use does not produce realistic, capability-based metrics to drive supportable operational decisions.

Finally, OAS conducted a thorough review of historical documents, aircraft modifications, and existing data sources in an effort to answer the sponsor's original questions. OAS also developed a sound methodology to analyze potential ROI but with limited availability of reliable data—the results proved inconclusive.

Recommendations

Methodology

Similar research efforts for any MDS will require reaccomplishment of the full HHM and ranking and filtering processes.

Root Causes and Indicators

- Apply the NEP methodology utilizing data from other units to verify potential gains.
- In order to most directly improve TNMCM, all levels of leadership would need to make TNMCM their primary metric.

TNMCM Standard

Develop a repeatable methodology to compute the standard that:

- Reflects day-to-day minimum operational requirements
- Adjusts to fully mobilized force capabilities and surge mobility requirements
- Accounts for historic capabilities and fleet resources

ROI

- To succinctly calculate an aircraft modification ROI, the Air Force needs to develop and implement better tracking methods to capture the required data needed for ROI calculations.
- Ensure data integrity is improved and maintained in the current maintenance data collection systems as well as in the future Expeditionary Combat Support System (ECSS).

Additional Recommendation

Incorporate the inputs from field personnel and this research into the ongoing ECSS blueprinting effort.

Notes

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I knew full well that the maintenance I was going to get would determine the success or failure of the operation. I must get the maximum performance out of the planes assigned to my command, or I would fail to do the job.

—Lt Gen William H.Tunner, USAF

The very serious responsibility for maintaining what we are given is based on the hard reality that we will never have all the equipment, supplies, facilities, and funds we require. On the battlefield, we will be short because of combat losses, accidents, interruptions in the supply system, or just insufficient resources to fill all needs. Thus, a well-trained soldier must be taught to maintain and conserve what he has—in peace and in war.

—Gen John A. Wickham, USA

…no success is possible—or even conceivable—which is not grounded in an ability to tolerate uncertainty, cope with it, and make use of it.

—Martin van Creveld

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Beyond Aut

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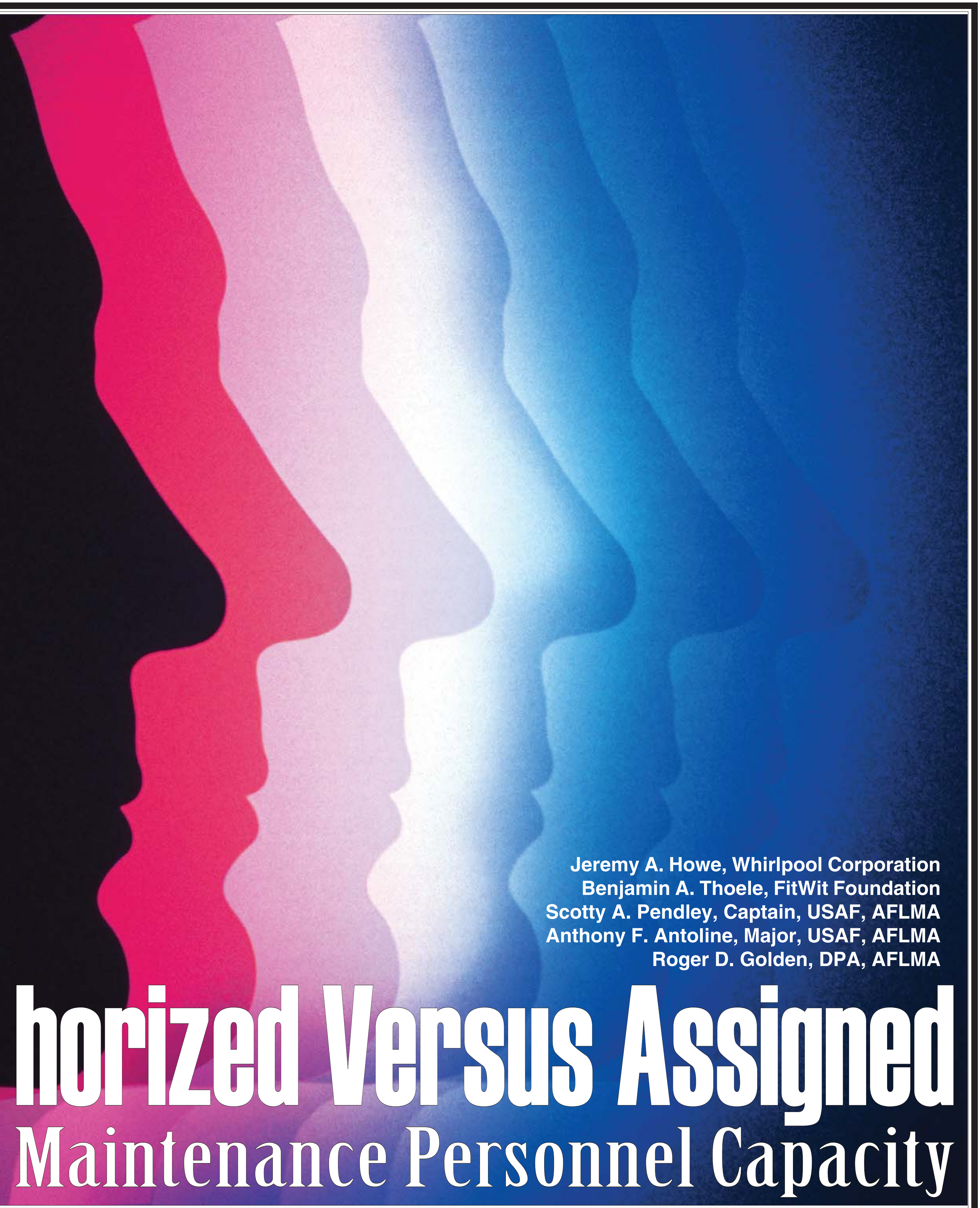
Introduction

Most would agree that aircraft maintenance has been and continues to be a challenging, complex task involving a delicate balance of resources to include personnel, equipment, and facilities. This balancing act occurs in a very hectic environment. The Air Force flies 430 sorties per day in support of Operation Iraqi Freedom and Enduring Freedom. A mobility aircraft takes off somewhere in world approximately every 90 seconds.[1] As the demand for aircraft continues to grow, the number of airmen who support these aircraft is declining. "Since 2001 the active duty Air Force has reduced its end-strength by almost 6 percent but our deployments have increased by at least 30 percent, primarily in support of the Global War on Terror."[2] This reduction in personnel is part of the Air Force's process of drawing down the total force by approximately 40,000 people, with many of these cuts in aircraft maintenance career fields. Also adding to the growing maintenance workload is an aircraft fleet which now averages almost 24 years old, with the average age still increasing.[3]

When it comes to aircraft maintenance, the Air Force depends on metrics to know whether or not we are measuring up to standards. Several metrics exist which attempt to measure the success or failure of our maintainers' efforts. One of the most recognized metrics is the total not mission capable maintenance (TNMCM) rate. Air Force Instruction 21-101 describes TNMCM as "perhaps the most common and useful metric for determining if maintenance is being performed quickly and accurately."[4] Although a lagging type indicator, it is one of several key metrics followed closely at multiple levels of the Air Force. Over the last several years, the TNMCM rate for many aircraft gradually increased. This fact was highlighted during a 2006 quarterly Chief of Staff of the Air Force Health of the Fleet review. Follow-on discussions ultimately resulted in the Air Force Materiel Command Director of Logistics (AFMC/A4) requesting the Air Force Logistics Management Agency (AFLMA) to conduct an analysis of TNMCM performance with the C-5 Galaxy aircraft as the focus. AFLMA conducted two studies in support of this request.

Background

The *C-5 TNMCM Study II* (AFLMA project number LM200625500) included five objectives. One of those objectives was to determine root causes of increasing TNMCM rates for the C-5 fleet. An extensive, repeatable methodology was developed and utilized to scope an original list of 184 factors down to two potential root causes to analyze in-depth for that particular study. These two factors were aligning maintenance capacity with demand, and the logistics departure reliability versus TNMCM paradigm. To address the root cause factor of aligning maintenance capacity with demand, a method of determining available maintenance capacity was needed. To meet this objective, a new factor designated as net effective personnel (NEP) was developed. NEP articulates available maintenance capacity in a more detailed manner that goes



Jeremy A. Howe, Whirlpool Corporation
Benjamin A. Thoele, FitWit Foundation
Scotty A. Pendley, Captain, USAF, AFLMA
Anthony F. Antoline, Major, USAF, AFLMA
Roger D. Golden, DPA, AFLMA

horized Versus Assigned Maintenance Personnel Capacity

Article Highlights

Ultimately, the NEP methodology has the potential to be used alone or in conjunction with the Logistics Composite Model to better portray maintenance personnel requirements and capabilities based on experience and skill levels.

"Beyond Authorized Versus Assigned: Aircraft Maintenance Personnel Capacity" quantifies the phrase "we need more people" beyond the traditional metric of authorized versus assigned personnel. The article is based on work done for a recent Air Force Logistics Management Agency project—*C-5 TNMCM Study II*. During this project, an extensive, repeatable methodology was developed and utilized to scope an original list of 184 factors down to two potential root causes. These two factors were aligning maintenance capacity with demand, and the logistics departure reliability versus TNMCM paradigm. To address the root cause factor of aligning maintenance capacity with demand, a method of determining available maintenance capacity was needed. To meet this need, a new factor designated as net effective personnel (NEP) was developed. NEP articulates available maintenance capacity in a more detailed manner that goes beyond the traditional authorized versus assigned viewpoint. The article describes how the NEP calculations were developed during the C-5 TNMCM Study II. The NEP calculations were ultimately used in conjunction with historical demand to propose base-level maintenance capacity realignments resulting in projected improvements in the C-5 TNMCM rate.

The ratio between authorized and assigned personnel is typically used to quantify personnel availability. While this ratio is an indicator of maintenance capacity, it provides only a limited beyond the traditional authorized versus assigned personnel viewpoint. The remainder of this article describes the need for NEP and how the NEP calculations were developed during the *C-5 TNMCM S*tudy II. The NEP calculations were ultimately used in conjunction with historical demand to propose base-level maintenance capacity realignments resulting in projected improvements in the C-5 TNMCM rate.

Personnel as a Constraint

The analytical methodology applied to the C-5 maintenance system determined that personnel availability was an important factor to consider. This idea is not new; indeed, the force-shaping measures underway in the Air Force have brought the reality of constrained personnel resources to the forefront of every airman's mind. Without exception, maintenance group leadership (MXG) at each base visited during the C-5 TNMCM Study II considered personnel to be one of the leading constraints in reducing not mission capable maintenance hours. The study team heard the phrase "we need more people" from nearly every shop visited:

> *"The biggest problem for the maintainers here is a shortage of people."*[5]
>
> *"With more people we could get a higher MC [mission capable]. We're currently just scrambling to meet the flying schedule."*[6]
>
> *"Hard-broke tails and tails in ISO [isochronal inspection] get less priority than the flyers. We run out of people—we physically run out."*[7]

The Air Force defines total maintenance requirements (authorizations) on the basis of the Logistics Composite Model (LCOM) and current manpower standards. LCOM is a stochastic, discrete-event simulation which relies on probabilities and random number generators to model scenarios in a maintenance unit and estimate optimal manpower levels through an iterative process. The LCOM was created in the late 1960s through a joint effort of RAND and the Air Force Logistics Command. Though intended to examine the interaction of multiple logistics resource factors, LCOM's most important use became establishing maintenance manpower requirements. LCOM's utility lies in defining appropriate production levels, but it does not differentiate experience.[8] Once these requirements are defined, the manpower community divides these requirements among the various skill levels as part of the programming process. Overall, the manpower office is charged with determining the number of slots, or spaces, for each skill level needed to meet the units' tasks. The personnel side then finds the right *faces*, or people, to fill the spaces.

One measure historically used to quantify personnel availability is the ratio between authorized and assigned personnel. While this ratio is an indicator of maintenance capacity, it provides only a limited amount of information. Authorized versus assigned ratios do not take into account the abilities and skill levels of the maintenance personnel, nor does it factor in the availability of the personnel on a day-to-day basis. These issues were addressed in the *C-5 TNMCM Study II* by quantifying "we need more people" beyond the traditional metric of authorized versus assigned personnel. This capacity quantification was done as part of the larger effort of aligning capacity with demand. The process of capacity planning generally follows three steps:

- Determine available capacity over a given time period
- Determine the required capacity to support the workload (demand) over the same time period
- Align the capacity with the demand[9]

The following describes how the study team pursued step 1, determining available capacity over a given time period, using data from the 436 MXG at Dover Air Force Base (AFB) and characterizing the results in terms of what the study team denoted as NEP.

Determining Available Capacity

When personnel availability and capacity are discussed at the organizational level, typically the phrase *authorized versus assigned* personnel is used. However, are all people assigned to maintenance organizations—namely, an aircraft maintenance squadron (AMXS) or a maintenance squadron (MXS)—viable resources in the repair process? Most maintainers will answer no. While it is true that all assigned personnel serve a defined and important purpose, not everyone in these organizations is a totally viable resource to be applied against maintenance demand. This impacts maintenance repair time and aircraft availability.

TNMCM time begins and ends when a production superintendent advises the maintenance operations center to change the status of an aircraft. The length of that time interval is determined by several things. One factor is the speed of technicians executing the repair, which includes diagnosis, corrective action, and testing (illustrated in Figure 1) the repair node of Hecht's *restore-to-service* process model.

As illustrated by the Hecht process model, there are other important components required to return an aircraft to service, but the pool of manpower resources required to support the repair node is critically linked to TNMCM time. Within a mobility aircraft maintenance organization, this pool represents hands-on 2AXXX technicians whose primary duty is performing aircraft maintenance. Specifically, the study team defined the technician resource pool as follows:

> **Technicians**: the collective pool of airmen having a 2AXXX AFSC, that are 3-level or 5-level maintainers, or nonmanager 7-level maintainers whose primary duty is the hands-on maintenance of aircraft and aircraft components.

The distinction of nonmanager 7-levels generally reflects 7-levels in the grades of E-5 and E-6. In active duty units, 7-levels in the grade of E-7 do not typically perform hands-on aircraft maintenance, but are instead directors of resources and processes—they are managers.[11] This is in stark contrast to Air National Guard units, where 2AXXX personnel in the senior noncommissioned officer ranks routinely perform *wrench-turning*, hands-on maintenance.[12] For the research detailed in the *C-5 TNMCM Study II*, personnel analysis centered on data from the 436 MXG at Dover AFB and utilized the study team's definition of technicians.

Net Effective Personnel

Authorized versus assigned personnel figures usually quantify the entire unit. With the definition of technicians in mind, it is

Article Highlights

amount of information. These ratios do not take into account the abilities and skill levels of the maintenance personnel, nor does it factor in the availability of the personnel on a day-to-day basis. The NEP methodology described in the article is a repeatable process which produces data that provides leadership with a better representation of the personnel resources and actual capacity available to an Air Force aircraft maintenance organization on a day-to-day basis. The NEP methodology will be tested further and validated using personnel data from other units to verify similar results and potential gains. Ultimately, the NEP methodology has the potential to be used alone or in conjunction with the Logistics Composite Model to better portray maintenance personnel requirements and capabilities based on experience and skill levels.

Article Acronyms

AFB – Air Force Base
AFLMA – Air Force Logistics Management Agency
AFSC – Air Force Specialty Code
AMXS – Aircraft Maintenance Squadron
ANGB – Air National Guard Base
APG – Aerospace and Powerplant General
CBT – Computer-Based Training
CMS – Component Maintenance Squadron
EMS – Equipment Maintenance Squadron
ETCA – Education and Training Course Announcement
LCOM – Logistics Composite Model
MXG – Maintenance Group
MXS – Maintenance Squadron
NEP – Net Effective Personnel
TDY – Temporary Duty
TNMCM – Total Not Mission Capable Maintenance

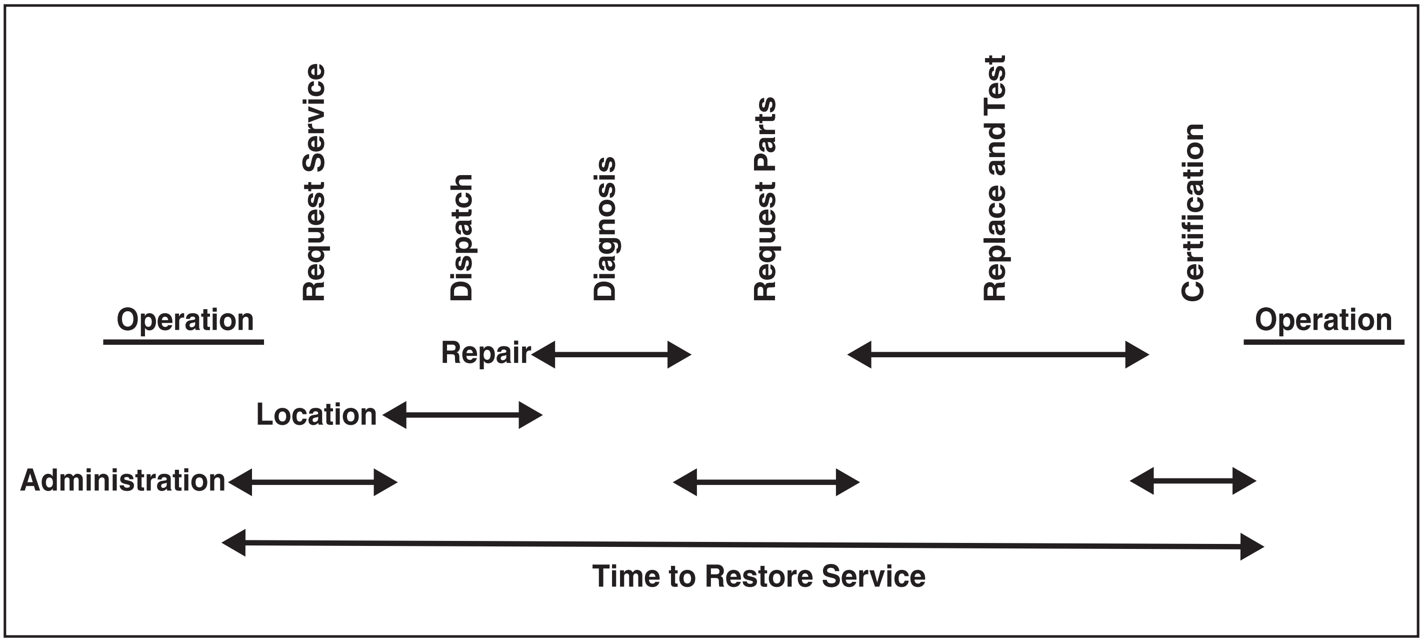


Figure 1. Time to Restore Service Process Model[10]

Technician Category	Productivity Factor
Non-manager 7-levels	100%
Non-manager 7-level trainers	85%
5-levels	100%
5-level trainers	85%
3-levels	40%

Table 1. Productivity Factors[15]

important to consider three additional factors that introduce variability into the personnel resource pool. These factors are:

- Skill-level productivity
- Ancillary and computer-based training (CBT)
- Availability

The study team examined the influence of these three factors, as well as their impact on the viable resource pool for the 436 MXG. This collective impact yielded a new resource pool representing a depiction of *effective* capacity rather than just the authorized versus assigned ratio. Again, this new resource pool is denoted as Net Effective Personnel, or NEP.

Factor 1: Skill-Level Productivity

In order to accurately examine the quantitative adequacy of a resource, as well as how a resource has historically been used to meet demand, there must be parity among individual resource units. Consider the previous definition of technicians. If one were to select two people at random, would they be equally capable resources? Not necessarily, if one was a 3-level trainee and the other was a 5 or 7-level resource. In order to collectively examine people in terms of comparable resources, and to account for the skill-level variability in typical aircraft maintenance organizations, productivity factors were applied to the resource pool.

As part of this research effort, the study team utilized its strategic partnership with RAND Project Air Force. Through personal interviews with RAND personnel and review of recently published RAND research, the study team learned that RAND had explored the productivity of trainees and trainers in aircraft maintenance units. Trainees were defined as 3-levels, who are not as productive as 5- and 7-levels. Additionally, some 5- and 7-levels were not as productive as others because they spend time training and instructing 3-level personnel.[13] In terms of specific productivity based on RAND research, 3-levels were estimated to be 40 percent productive, 5-level trainers and nonmanager 7-level trainers were estimated to be 85 percent productive, and 5-levels and nonmanager 7-levels were 100 percent productive if they were unencumbered with training responsibilities.[14] For the purpose of this analysis, the number of trainers was considered to be equal to the number of 3-levels assigned—a one-to-one ratio. The productivity factors for the viable resource pool are summarized in Table 1.

These productivity factors also are similar to results from additional RAND research at Travis AFB published in 2002.[16] Considering the productivity factors from Table 1, the net effect of these productivity factors alone was a reduction of the 436 AMXS viable resource pool by an average of 5.68 percent.[17]

Factor 2: Ancillary Training and Computer-Based Training

In recent times the impact of ancillary training and CBT has been such an important issue for Air Force senior leaders, that it was the sole topic of the airman's Roll Call of 9 February 2007.[18] This document indicated that some active duty airmen spend disproportionate amounts of time on ancillary training, which detracts from their ability to perform official duties. Moreover, the document suggested that some ancillary training may no longer be relevant.[19] In the context of the viable pool of aircraft maintenance technicians, this would mean that, some of the time, personnel resources may be on duty but unavailable to perform hands-on maintenance due to an ancillary training requirement.

A consensus majority of personnel interviewed during the study team's site visits echoed these concerns, describing an *insidious growth* of new training requirements in recent years.[20] An additional concern voiced by interviewees pertained to computer resources. Interviewees described a situation where office workers have ready access to a personal computer (PC), but dozens of maintenance technicians often share only a handful of communal PCs. Consequently, their ability to complete computer-based ancillary training is constrained. One unit training manager explained that in the past, a group training briefing would be conducted for an entire work center, fulfilling each individual's training requirement simultaneously.[21] Today, an online course issues the required certificate of completion for only one individual, thereby necessitating that each airman conduct the training individually. The net result is more time away from primary duties (for example, repairing aircraft). In order to assess the influence of ancillary training and CBT on the technician resource pool, the study team quantified the average daily impact.

A list of various ancillary and computer-based training items that are applicable to the relevant pool of aircraft maintenance personnel was collected from three data sources:

- The USAF Education and Training Course Announcement (ETCA) Website[22]
- The unit training monitor at the AFLMA
- The unit training monitor for the 105 MXG at Stewart Air National Guard Base (ANGB)

The training was categorized by data source, course number (if applicable), and course name. Training was also categorized as follows.

- Mandatory for all personnel, such as law of armed conflict training
- Voluntary or job-specific, such as hazardous material management training

Also, requirements were identified by the recurrence frequency (one-time, annual, or semiannual). Some requirements are aligned with the 15-month aerospace expeditionary force cycle; this would equate to a yearly recurrence frequency of 0.8 (12/15). Finally, training was categorized by the duration in hours for each requirement as identified by the data sources.

Most training courses only take up a portion of the duty day. The average duration for courses considered was 2.8 hours, with many listed at one hour or less. In situations like these, a manager would still view the individual as *available* for the duty day.[23] Therefore, the study team examined the impact of CBT and ancillary training as a separate factor and not as a part of the availability factor (factor 3). Final calculations resulted in the following totals:

- Hours of mandatory one-time training (denoted M_o), 101.5 hours
- Hours of mandatory annually-recurring training (M_a), 67.2 hours
- Voluntary or job-specific one-time training (VJS_o), 85.8 hours
- Voluntary or job-specific annually-recurring training (VJS_a), 10.3 hours

In order to quantify the daily impact of these training items, the study team made the following assumptions:

- An 8-hour workday
- 220 workdays in a calendar year. (5 days per week x 52 weeks per year) = 260; 260 – (30 days annual leave) – (10 federal holidays[24]) = 220 workdays
- 3-levels required all of the mandatory, one-time training
- 5-levels and 7-levels required only the annually-recurring portion of the mandatory training
- As an average, all 3-levels required 10 percent of the voluntary or job-specific, one-time training
- As an average, all 5-levels and 7-levels required 10 percent of the voluntary or job-specific, one-time, annually-recurring training
- As an average, all training durations would be increased 20 percent to account for travel, setup, and preparation[25]

When employing the above assumptions, the figures in Table 2 were calculated to be best estimates of the time impact of ancillary training and CBT.

The best estimates for CBT and ancillary training requirements account for 7.51 percent and 5.24 percent of the workday for 3-, 5-, and 7-levels, respectively. The complementary effectiveness rates for this factor are expressed as 0.9249 (1 – 0.0751) for 3-levels and 0.9476 (1 – 0.0524) for 5 and 7-levels. These rates are listed as the ancillary and CBT factors for 3-, 7-, and 5-levels respectively in Table 6.

Table 3 illustrates how these rates change when the percentages of voluntary and job-specific training (V/JST) or the percentage of travel and setup buffer are varied. The matrices in Table 3 illustrate the results of sensitivity analysis of various CBT and ancillary training factors that would result for combinations of voluntary or job-specific training, or travel and setup buffer ranging from zero to 25 percent. The range of all calculated factors is approximately 3 percent for both technician categories. Note that the CBT and ancillary training factors chosen utilizing the study team's assumptions are boxed and shaded. For both 3-, 5-, and 7-levels, the calculated training factors fall very near the mean developed in the sensitivity analysis. Some values shown in Table 3 are the result of rounding. For the 436 MXG at Dover AFB, the net effect of these CBT and ancillary training factors alone was a reduction of the viable resource pool by an average of 1.58 percent.[26]

Technician	Hours per Year	Hours per Workday	Percentage of 8-Hour Workday	Minutes per Workday
3-level	132.10	0.60	7.51%	36.03
Formula	$1.2(M_o+(0.1VJS_o))$	(Hrs/yr)/220	(Hrs/workday/8)*100	(Hrs/workday)*60
5- / 7-level	92.17	0.42	5.24%	25.1
Formula	$1.2(M_a+(0.1(VJS_o+VJS_a))$	(Hrs/yr)/220	(Hrs/workday/8)*100	(Hrs/workday)*60

Table 2. Best Estimate of CBT and Ancillary Training Time Requirements

3-Levels						
	% Travel/Setup Multiplier					
% V/JST	1	1.05	1.1	1.15	1.2	1.25
0.00	0.942	0.939	0.937	0.934	0.931	0.928
0.05	0.940	0.937	0.934	0.931	0.928	0.925
0.10	0.937	0.934	0.931	0.928	**0.925**	0.922
0.15	0.935	0.932	0.929	0.925	0.922	0.919
0.20	0.933	0.929	0.926	0.922	0.919	0.916
0.25	0.930	0.927	0.923	0.920	0.916	0.913
5- and 7-Levels						
	% Travel/Setup Multiplier					
% V/JST	1	1.05	1.1	1.15	1.2	1.25
0.00	0.962	0.960	0.958	0.956	0.954	0.952
0.05	0.959	0.957	0.955	0.953	0.951	0.949
0.10	0.956	0.954	0.952	0.950	**0.948**	0.945
0.15	0.954	0.951	0.949	0.947	0.944	0.942
0.20	0.951	0.948	0.946	0.944	0.941	0.939
0.25	0.948	0.946	0.943	0.940	0.938	0.935
Descriptive Statistics						
	Mean	Min	Max	Range		
3-Level	0.928	0.913	0.942	0.030		
5- and 7-Level	0.949	0.935	0.962	0.027		

Table 3. CBT and Ancillary Training Factor Sensitivity Analysis

		3-Level	5-Level	7-Level	Total	% of Total
	Assigned	32	28	22	82	100%
Reason Unavailable	Temporary Duty		6	4	10	12%
	Qualification and Training Program	9			9	11%
	Detail	2	3	2	7	9%
	Leave	2	3	2	7	9%
	Scheduled Off Day	2	1	2	5	6%
	Medical Profile		2	1	3	4%
	Part-day Appointment	1	1	1	3	4%
	Full-day Appointment			2	2	2%
	Compensatory Off Day			1	1	1%
	Flying Crew Chief Mission		1		1	1%
	Out Processing		1		1	1%
	Permanent Change of Assignment		1		1	1%
	Field Training Detachment Course		1		1	1%
	First Term Airmen's Center	1			1	1%
	Bay Orderly	1			1	1%
	Available	14	8	7	29	35%

Figure 2. 436 AMXS APG Day Shift Personnel Availability Snapshot[27]

Factor 3: Availability

Manpower resources must be present to be viable, and on any given day, aircraft maintenance organizations lose manpower resources due to nonavailability. Examples include temporary duty (TDY) assignments, sick days, and other details. To illustrate, Figure 2 depicts the actual availability of 436 AMXS airframe and powerplant general (APG) technicians on day shift for Thursday, April 12, 2007. For this work center, on this particular day and shift, roughly 65 percent of assigned technicians were not available for the various reasons listed.

Much like aircraft maintenance, some events that take people away from the available pool are scheduled and known well in advance, while others are unexpected, such as illnesses and family emergencies.

Although scheduled and unscheduled events both have an impact, scheduled events are anticipated and can be planned for. Adjustments can be made and resources can be shifted. Consequently, resource managers want to monitor and manage scheduled personnel nonavailability to the greatest extent possible. In order to assess the impact of this factor on the resource pool, the study team monitored the personnel availability of the 436 AMXS at Dover AFB from 1 March through 30 April 2007 via 9 weekly snapshots. 436 AMXS supervision tracks manpower via a spreadsheet tool that identifies the availability status of each assigned 3-level, 5-level, and nonmanager 7-level in their hands-on maintenance resource pool. For AMXS, this represents technicians from six different shops, identified with the corresponding Air Force specialty codes (AFSC) as follows:

- Airframe and Powerplant General (APG) – 2A5X1C, 2A5X1J
- Communication and Navigation (C/N) – 2A5X3A
- Electro/Environmental Systems (ELEN) – 2A6X6
- Guidance and Control (G/C)[28] – 2A5X3B
- Hydraulics (HYD) – 2A6X5
- Engines (JETS) – 2A6X1C, 2A6X1A

The AMXS snapshot spreadsheet is updated (but overwritten) continually as status changes occur.[29] By monitoring changes in these snapshots, the study team was able to examine not only the impact of personnel nonavailability in aggregate, but also the degree to which the discovery and documentation of events altered the size of the capacity pool. Using the Dover AMXS snapshots, the study team calculated the number of available technicians in the aircraft maintenance resource pool.

The study team monitored the actual availability figures for the 436 AMXS over the 9-week period of March and April 2007, for a total of $n = 61$ daily observations. Across all shifts, the total number of personnel assigned to the AMXS personnel resource pool was 411 for the month of March, and 412 for the month of April. Actual availability figures, however, were much lower. Table 4 summarizes the descriptive statistics of this analysis.

The upper row of Table 4 statistics reflects the actual number of technicians available, while the bottom row reflects that number as a percentage relative to the total number of technicians assigned. For example, in the month of March, the maximum number of available technicians observed was 202, or 49 percent (202 of 411) of the total assigned. The mean availability for March was 36 percent. These figures take into consideration that some of the nonavailable personnel may be performing duties elsewhere for the Air Force such as flying crew chief missions or other TDY assignments. Therefore, they would not be viable assets for the aircraft maintenance resource pool at Dover AFB. The net effect of this nonavailability factor was a reduction of the AMXS home station viable resource pool by an average of 65.39 percent. This is reflected as the 35 percent mean highlighted for March-April 2007.

As discussed previously with Factors 1 and 2, the productivity of available technicians is reduced due to skill-level training needs, as well as ancillary and CBT training requirements. The study team applied productivity factors from Table 1 and CBT and ancillary training factors from Table 2 to the observed number of available technicians in AMXS. These calculations quantified the final pool of viable personnel resources, which is denoted as NEP. Because of daily variations in the number of 3-, 5-, and 7-skill level technicians available, the factors were applied to each daily observation. In performing these calculations, the study team developed a representation of the effective personnel resource pool. Specifically, the NEP figures account for the realities of availability and productivity, and allow the resource pool to be viewed objectively, unconstrained by concerns such as skill-level differences. The value of such a resource picture is that it provides a suitable mechanism for comparing maintenance capacity (NEP resource pool) with maintenance demand. The summary descriptive statistics for the 436 AMXS NEP are indicated in Table 5. Averaging across the observed timeframe, the 436 AMXS had approximately 113 net effective technicians in its viable resource pool on any given day. This figure is approximately 27 percent of the total assigned quantity of technicians, again using the previously discussed definition for technicians.

Therefore, to arrive at the results shown in Table 5, the study team considered the factors from Table 1 and 2, as well as the ancillary and CBT factors complimentary effectiveness rates calculated.

Each factor and rate detailed to this point was assigned a new designation for ease of use in the proposed NEP equation. The newly designated factors, factor descriptions, and the associated values are listed in Table 6.

The T factors relate to training, the A factors relate to available personnel, and the P factors relate to productivity. These factors

411 Assigned	March 07				April 07				March-April 07			
	Min	Max	Mean	Range	Min	Max	Mean	Range	Min	Max	Mean	Range
Available	100	202	**147**	102	104	163	**137**	59	100	202	**142**	102
% of Assigned	24%	49%	**36%**	25%	25%	40%	**33%**	14%	24%	49%	**35%**	25%

Table 4. 436 AMXS Availability Descriptive Statistics

411 Assigned	March 07				April 07				March-April 07			
	Min	Max	Mean	Range	Min	Max	Mean	Range	Min	Max	Mean	Range
Available	79	167	**120**	88	77	124	**105**	47	77	167	**113**	90
% of Assigned	19%	41%	**29%**	21%	19%	30%	**26%**	11%	19%	41%	**27%**	22%

Table 5. 436 AMXS NEP Descriptive Statistics

Factor	Description	Value
T_{75}	Ancillary/CBT Factor for 7- and 5-levels	0.948
A_{75NT}	The number of available nonmanager 7-levels and 5-levels who are not trainers	Varies day-to-day
P_t	Trainer Productivity	0.85
A_{75T}	The number of available nonmanager 7-levels and 5-levels who are trainers	Varies day-to-day
T_3	Ancillary/CBT Factor for 3-levels	0.925
P_e	Trainee Productivity	0.4
A_3	The number of available 3-levels	Varies day-to-day

Table 6. NEP Factors

were applied to the number of available technicians as recorded in the AMXS availability snapshots using the newly proposed NEP calculation, shown as Equation 1. Equation 1 is the cumulative NEP equation which accounts for all three factors which create variability in the resource pool and yields a numerical quantity of net effective personnel. To determine the NEP percentage, one need simply divide the right side of the equation by the number of assigned technicians (7-level nonmanagers, 5-levels, and 3-levels).

Figure 3 provides an Excel spreadsheet snapshot of an example NEP calculation for a generic maintenance unit. The maintenance unit's NEP is calculated using Equation 1 by entering the personnel totals in each of the five categories in the left column. These values are then multiplied by the factors in the right column to determine NEP. In this example, the unit has 104 technicians available but the NEP is only 77. In other words, the practical available maintenance capacity is only 77 technicians, not 104 as it initially appears.

To summarize, the study team's arrival at NEP followed an iterative sequence of three factor reductions:

- Skill-level productivity differences, to include those for trainees and trainers
- Ancillary training and CBT
- The nonavailability of personnel

$$NEP = T_{75}(A_{75NT} + (P_t A_{75T})) + T_3(P_e A_3)$$

Equation 1. Net Effective Personnel

Figure 4 graphically illustrates these iterations based on the relative size of the impact of the three factors on reductions to the overall resource pool. As shown in Figure 4, nonavailability had the biggest impact, productivity factors were next, and finally the effect of CBT and ancillary training had the smallest impact.

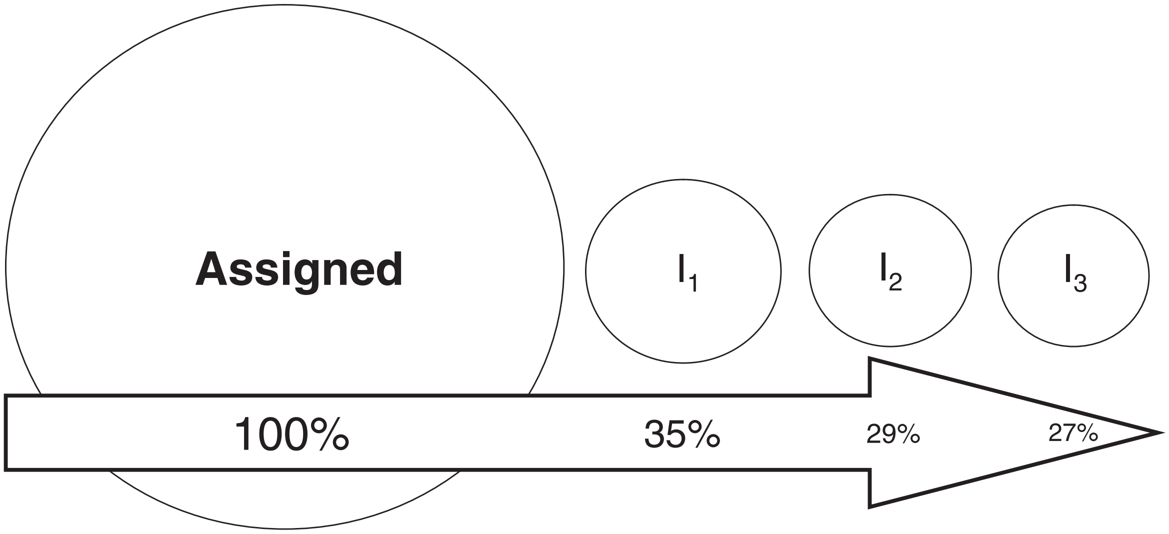
In addition to AMXS, an Air Force Maintenance Group usually includes a separate equipment maintenance squadron (EMS) and component maintenance squadron (CMS). However, if total authorizations are under 700, EMS and CMS will be combined into a maintenance squadron such as the MXS at Dover AFB. Various flights within a typical MXS maintain aerospace ground equipment, munitions, off-equipment aircraft and support equipment components; perform on-equipment maintenance of aircraft and fabrication of parts; and provide repair and calibration of test, measurement, and diagnostic equipment.[30] Technicians assigned to MXS usually perform maintenance not explicitly linked to the launch and recovery of aircraft (as is the focus of AMXS). However, some MXS personnel directly support flight line activities.

A more complete representation of the net effective personnel pool for aircraft maintenance resources in an MXG would include not only personnel in AMXS, but also those in MXS. The number of nonmanager 7-levels, 5-levels, and 3-levels assigned to the 436 MXS was determined from Air Force Personnel Center data to be 318.[31] Using the study team's definition of technician, this results in 729 technicians in the 436 MXG (411 in AMXS plus 318 in MXS). However, because the study team could not obtain exact daily availability figures for MXS similar to those of AMXS, the study team applied each of the calculated daily NEP percentages for AMXS against the number of assigned technicians to MXS. This calculation yielded daily estimates of the number of NEP for MXS. Since AMXS and MXS are both aircraft maintenance units with many of the same AFSCs and similar demands on their personnel, any differences from actual numbers as a result of this method were considered negligible for this analysis.

The study team then added the AMXS NEP figures to the MXS NEP figures, resulting in a collective NEP figure for the flight line maintainers at Dover AFB. These collective NEP

# of available 3-levels	30	CBT Factor (3-levels)	0.925
# of available 5-levels who are trainers	30	CBT Factor (5/7-levels)	0.948
# of available 5-levels who are **not** trainers	32	Productivity Factor (trainees)	0.400
# of available non-manager 7-levels who are trainers	0	Productivity Factor (trainers)	0.850
# of available non-manager 7-levels who are **not** trainers	12		
NEP	77.0		

Figure 3. Example NEP Calculation



- Iteration 1 (I_1) : Availability
  - $A_{75NT} + A_{75T} + A_3$
- Iteration 2 (I_2) : Availability and Productivity
  - $A_{75NT} + P_t A_{75T} + P_e A_3$
- Iteration 3 (I_3) : Availability, Productivity, CBT and Ancillary Training
  - $T_{75}(A_{75NT} + P_t A_{75T}) + T_3(P_e A_3)$

Figure 4. The Iterations of NEP

figures are shown in Table 7. The upper portion of the table shows the NEP figures grouped by columns (day of the week) with each row representing 1 of the 9 weeks over the entire period that data was tracked. The bottom section of Table 7 also displays the descriptive statistics for NEP across both AMXS and MXS combined. The highest average NEP value was 222 on Thursdays, representing approximately 30 percent of the baseline total of 729 people.

Conclusion

The ratio between authorized and assigned personnel is typically used to quantify personnel availability. While this ratio is an indicator of maintenance capacity, it provides only a limited amount of information. These ratios do not take into account the abilities and skill levels of the maintenance personnel, nor does it factor in the availability of the personnel on a day-to-day basis. The Net Effective Personnel methodology described in this article is a repeatable process which produces NEP figures that provide leadership with a better representation of the personnel resources and actual capacity available to an Air Force aircraft maintenance organization on a day-to-day basis. The NEP methodology will be tested further and validated using personnel data from other units to verify similar results and potential gains. Ultimately, the NEP methodology has the potential to be used alone or in conjunction with LCOM to better portray maintenance personnel requirements and capabilities based on experience and skill levels.

As previously mentioned, the NEP methodology described in this article was developed as part of the larger *C-5 TNMCM Study II*. The entire study can be found at the Defense Technical Information Center Private Scientific and Technical Information Network Website at https://dtic-stinet.dtic.mil/.

End Notes

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	Day of the Week NEP Distributions						
	Sun	Mon	Tue	Wed	Thu	Fri	Sat
NEP	186	219	228	211	259	219	187
	148	209	226	219	213	182	140
	153	212	211	242	219	195	155
	188	242	289	297	245	205	169
	165	210	220	216	294	235	198
	137	186	187	195	205	175	148
	173	206	192	188	194	176	168
	167	213	201	195	183	186	174
	176	203			185	194	180
n	9	9	8	8	9	9	9
Min	137	186	187	188	183	175	140
Max	188	242	289	297	294	235	198
Mean	166	211	219	221	222	196	169
% of Assigned	23%	29%	30%	30%	30%	27%	23%
Range	51	56	102	109	110	59	58
Variance	300	221	1031	1241	1385	404	349
Standard Dev	17	15	32	35	37	20	19

Table 7. Day of the Week NEP Distributions for 436 MXG (AMXS and MXS)[32]

9. J.R.T. Arnold and S. Chapman, *Introduction to Materials Management*, 5th ed., Pearson Education, 2003, 244.
10. Herbert Hecht, *Systems Reliability and Failure Prevention*, Norwood, MA: Artech House Inc., 2004.
11. John G. Drew, Kristin F. Lynch, Jim Masters, Robert S. Tripp, and Charles Robert Roll, Jr., *Maintenance Options for Meeting Alternative Active Associate Unit Flying Requirements*, Santa Monica, California: RAND Corporation, MG-611-AF, 2008.
12. *Ibid*.
13. *Ibid*.
14. *Ibid*.
15. *Ibid*.
16. Dahlman, et. al., 132.
17. This figure represents data from the 436 AMXS for March-April 2007.
18. "Ancillary Training," *Airman's Roll Call*, [Online] Available: http://www.af.mil/shared/media/document/AFD-070209-083.pdf, accessed 9 February 2007.
19. *Ibid*.
20. Study team notes from meeting with 436 MOS Supervision, 9 January 2007.
21. 436 AMXS/MXAA, Dover AFB, March – April 2007.
22. "Education and Training Course Announcement," ETCA Website, [Online] Available: https://etca.randolph.af.mil/, accessed 21 March 2007.
23. *Ibid*.
24. US Office of Personnel Management, "Federal Holidays," [Online] Available: http://www.opm.gov/fedhol/, 11 April 2007.
25. It should be noted that the study team performed sensitivity analysis on the last three assumptions. See Table 3.
26. 436 AMXS/MXAA.
27. Data for 12 April 2007, 436 AMXS/MXAA, Dover AFB.
28. G/C is alternatively known as Automatic Flight Controls & Instruments.
29. 436 AMXS/MXAA.
30. *Ibid*.
31. Air Force Personnel Center, data pull, 27 March 2007.
32. Values in Table 7 are rounded to nearest whole number.

If I had to sum up in a word what makes a good manager, I'd say decisiveness. You can use the fanciest computers to gather the numbers, but in the end you have to set a timetable and act.

—Lido Anthony (Lee) Iacocca

If opportunity doesn't knock, build a door.

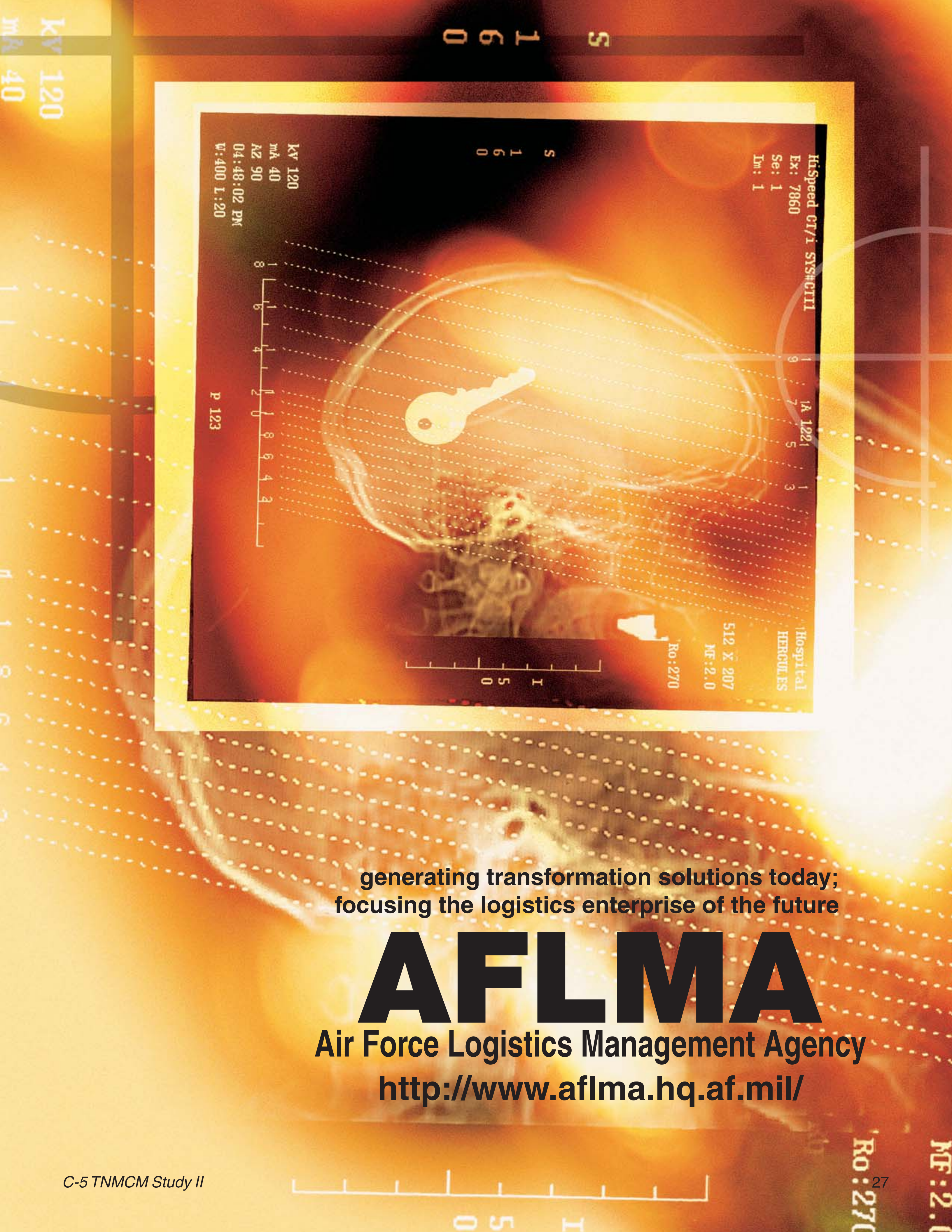
—Milton Berle

Ability is of little account without opportunity.

—Napoleon Bonaparte

Who bravely dares must sometimes risk a fall.

—Tobias George Smollett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Aligning

Introduction

Metrics are often used as roadmaps to help us know where we have been, where we are going, and how or if we are going to get there.[1] Metrics should generally be used to gauge organizational effectiveness and efficiency and to identify trends, not as a pass or fail indicator. Individually, they are snapshots in time.[2] Metrics are a statement of what is important to your organization and embody a way of thinking about your business; when metrics change, so does people's point of view. But what exactly is a metric and what constitutes a good versus bad metric?

Air Force Instruction (AFI) 21-101, *Aircraft Equipment and Maintenance Management,* describes metrics, specifically maintenance management metrics, as a crucial form of information used by maintenance leaders to improve the performance of maintenance organizations, equipment, and people when compared with established goals and standards.[3] AFI 21-101 also lists four attributes for metrics including:

- Accurate and useful for decisionmaking
- Consistent and clearly linked to goals and standards
- Clearly understood and communicated
- Based on a measurable, well-defined process[4]

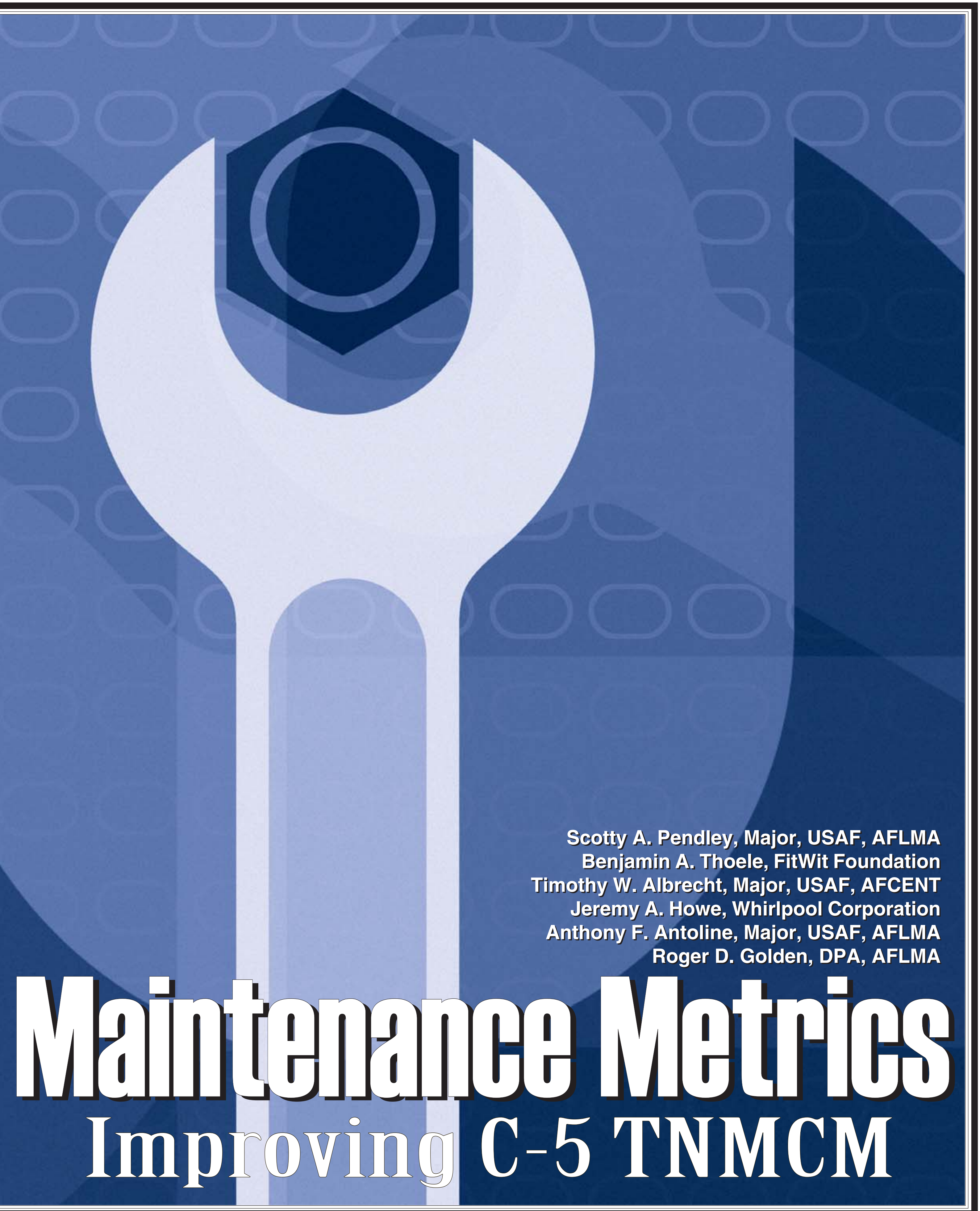
Dr Michael Hammer, a recognized leader in the field of process reengineering, also notes four principles of measurement.

- Measure what matters, rather than what is convenient or traditional
- Measure what matters most, rather than everything
- Measure what can be controlled, rather than what cannot be controlled
- Measure what has impact on desired business goals, rather than ends in themselves[5]

Hammer also points out several flaws with traditional metrics such as too many, fragmented, disorganized, internally focused, irrelevant to the customer, not used systematically, and not aligned with goals.[6] It is this last flaw (metrics not aligned with goals) which became a focus of examination during an Air Force Logistics Management Agency (AFLMA) study of rising Air Force total not mission capable maintenance (TNMCM) rates and potential root cause factors affecting these rates.

Background

At the request of the Air Force Materiel Command Director of Logistics (AFMC/A4), AFLMA conducted an analysis in 2006-2007 of TNMCM performance with the C-5 Galaxy aircraft as the focus. The *C-5 TNMCM Study II* included five objectives. One of those objectives was to determine root causes of increasing TNMCM rates for the C-5 fleet. To achieve that particular objective, an extensive, repeatable methodology was



Scotty A. Pendley, Major, USAF, AFLMA
Benjamin A. Thoele, FitWit Foundation
Timothy W. Albrecht, Major, USAF, AFCENT
Jeremy A. Howe, Whirlpool Corporation
Anthony F. Antoline, Major, USAF, AFLMA
Roger D. Golden, DPA, AFLMA

Maintenance Metrics

Improving C-5 TNMCM

Article Highlights

Realignment of metrics must start at the highest levels of the Mobility Air Force (MAF). The MAF should choose its value measure and create a set of metrics aligned with that measure.

At the request of the Air Force Materiel Command Director of Logistics, AFLMA conducted an analysis in 2006-2007 of total not mission capable maintenance (TNMCM) performance with the C-5 Galaxy aircraft as the focus. The *C-5 TNMCM Study II* included five objectives. One of those objectives was to determine root causes of increasing TNMCM rates for the C-5 fleet. To achieve that particular objective, an extensive, repeatable methodology was developed and utilized to scope an original list of 184 TNMCM factors down to two root causes for in-depth analysis. Those two factors were aligning maintenance capacity with demand and the logistics departure reliability versus the TNMCM paradigm. This article details the analysis of the second of these two factors.

This second factor was also described as a disconnect or misalignment between the C-5 maintenance group leadership's primary metric, home station logistics departure reliability (HSLDR), and one of the major command and Air Force senior leadership's primary metrics, aircraft availability. The remainder of this article describes how real-world and simulated data supported the early hypothesis that HSLDR and TNMCM were not aligned metrics. Finally, a brief discussion explains why the study team believed a disconnect existed between the base-level and command-level metrics.

The research demonstrated that HSLDR is aligned with neither aircraft availability nor TNMCM, as there is only a weak correlation between them. Maintainers at the wing level work to support operational effectiveness; however, higher levels of Air Force supervision appear more focused on improving strategic readiness. This disconnect in priorities was determined to be a root cause of the C-5 TNMCM rate being below Air Force standards.

If the Air Force's primary goal is to improve the C-5 fleet TNMCM rate, then priorities of the maintainers in the field must change. As the maintenance group (MXG) leadership focuses on HSLDR performance, not TNMCM, the MXP

developed and utilized to scope an original list of 184 TNMCM factors down to two root causes for in-depth analysis. Those two factors were aligning maintenance capacity with demand and the logistics departure reliability (LDR) versus TNMCM paradigm. This article details the analysis of the second of these two factors.

This second factor was also described as a disconnect or misalignment between the C-5 maintenance group (MXG) leadership's primary metric, home station logistics departure reliability (HSLDR), and one of the major command (MAJCOM) and Air Force senior leadership's primary metrics, aircraft availability (AA). The remainder of this article describes how real-world and simulated data supported the early hypothesis that HSLDR and TNMCM were not aligned metrics. Finally, a brief discussion explains why the study team believed a disconnect existed between the base-level and command-level metrics.

Primary Metrics of C-5 Maintenance Leadership

The *C-5 TNMCM Study II* originated because the project sponsor placed significant importance on TNMCM rates. Based on site visits and feedback from all but one C-5 MXG commander (MXG/CC) or other MXG senior leaders, the study team determined that the primary metric of the MXG/CC was HSLDR. AA, which is directly related to the TNMCM rate, was a primary metric of higher level leadership. Major General McMahon, then AMC director of logistics (AMC/A4), spoke to the study team in December 2006 concerning aircraft availability as the future cornerstone maintenance metric (as opposed to mission capable [MC) rates].[7] Similarly, personnel from the AMC/A4M office stated that aircraft availability is the number one concern for AMC Headquarters as opposed to MC rates.[8]

During site visits to Dover Air Force Base (AFB), Stewart Air National Guard Base, and Westover Air Reserve Base, the study team received feedback from base-level maintenance leadership concerning maintenance metrics. Some of the comments included:

> "We don't manage by MC-Rate…we don't chase the numbers. We care about departure reliability, and [the Air Force] should be looking at en route reliability."[9]

> "We don't look at the TNMCM rate…numbers aren't the issue. We focus on the mission and the flying schedule."[10]

> "What's important? Anything that makes us fly. The metric for the base is departure reliability…Ops isn't happy with a 73 percent LDR."[11]

> "MC rate is way down on the list of things we pay attention to…We're currently scrambling to meet the flying schedule. Our priorities go to the scheduled aircraft."[12]

> "Our primary metric is LDR."[13]

Based on feedback from AFMC/A4 and AMC/A4 leadership, MXG/CCs at three C-5 bases, and telephone discussions with MXG leadership at other C-5 bases, the study team concluded that the primary metric of the MAJCOM A4 leadership was AA, which includes TNMCM, and that the primary metric of the MXG/CCs was HSLDR.

HSLDR, TNMCM, and AA Defined

AFI 21-101 defines the HSLDR, TNMCM, and AA metrics and their uses. Additional insight on the use of these metrics can be found in the *Metrics Handbook for Maintenance Leaders*.

Home-Station Logistics Departure Reliability (HSLDR) Rate. This is a leading metric used primarily by the Mobility Air Forces (MAF) for airlift aircraft. This delineates down to only first-leg departures of unit-owned aircraft departing home station.[14]

HSLDR Rate (%) = ((# of HS Departures – # of HS Logistics Delays)/# of HS Departures) x 100

Total Not Mission Capable Maintenance (TNMCM) Rate. TNMCM rate is the average percentage of possessed aircraft (calculated monthly or annually) that are unable to meet primary assigned missions for maintenance reasons…. Any aircraft that is unable to meet any of its wartime missions is considered not mission capable (NMC). The TNMCM is the amount of time aircraft are in NMCM [not mission capable maintenance] plus not mission capable both (NMCB) status.[15]

NMCB is mentioned in AFI 21-101 as the percentage of unit-possessed hours that aircraft are not mission capable due to both maintenance and supply.[16]

TNMCM (%) = ((NMCM Hrs + NMCB Hrs)/ Unit Possessed Hrs) x 100

Aircraft Availability (AA) Rate. Aircraft availability is the percentage of a fleet that is in neither depot possessed status nor unit possessed NMC status.[17]

AA (%) = (MC Hours/Total Possessed Hrs) x 100

Note that TNMCM rate and AA rate are both part of the family of metrics that relate to aircraft status hours. Also important to remember is that unit possessed aircraft must be in one of four statuses:

- MC (to include partially mission capable for maintenance or supply)
- NMCM
- Not mission capable supply (NMCS)
- NCMB

Therefore, the percentage of MC hours must decrease as the percentage of NMCM, NMCS, and NMCB hours increase.

Metrics at Different Levels of the Organization

One might expect two different levels of an organization to have two different primary metrics. For the Air Force, the focus at the base maintenance level is expected to be on the tasks at hand to execute the mission on a daily basis. However, a strategic focus at the command A4 level is to be expected, looking across the availability of the entire fleet. Consider Dr Michael Hammer's presentation of this phenomenon in Table 1.

Article Highlights

simulation indicated that improving the TNMCM rate would require an increase in resources. Therefore, in order to improve the TNMCM rate without increased resources, the maintainers in the field must make TNMCM a priority. While it is impossible to model the current system perfectly, the results suggest that current maintenance policies do not ensure TNMCM improvement, but do improve HSLDR, which is the stated priority of the MXG leadership. Therefore, the study team recommended that MAJCOM leadership and MXG leadership decide on a set of metrics that are better aligned toward the same goal.

Article Acronyms

AA – Aircraft Availability
AFB – Air Force Base
AFI – Air Force Instruction
AFLMA – Air Force Logistics Management Agency
AFMC – Air Force Materiel Command
AMC – Air Mobility Command
D&C – Delays and Cancellations
Est TNMCM – Estimated TNMCM
FIFO – First In First Out
FY – Fiscal Year
HS – Home Station
HSLDR – Home Station Logistics Departure Reliability
LDR – Logistics Departure Reliability
LIFO – Last In First Out
MAF – Mobility Air Force
MAJCOM – Major Command
MC – Mission Capable
MCO – Maintenance Carryovers
MCR – Mission Capable Rate
MDR – Maintenance Dispatch Reliability
MOS – Maintenance Operations Squadron
MX – Maintenance
MXG – Maintenance Group
MXP – Maintenance Priority
NMC – Not Mission Capable
NMCB – Not Mission Capable Both
NMCM – Not Mission Capable Maintenance
NMCS – Not Mission Capable Supply
REMIS – Reliability and Maintainability Information System
TDR – Technical Dispatch Reliability
TNMCM – Total Not Mission Capable Maintenance
UAOOS – Unscheduled Aircraft Out of Service

The first column in Table 1 lists the various categories across the spectrum of oversight for an organization, ranging from enterprise goals to local activities. The headings in the top row list the range of positions in the hierarchy of jobs within the organization. In general, senior leaders are primarily accountable for setting the vision and strategy across the entire business enterprise. Process owners are responsible for developing and executing operations and processes to support higher strategy, while professionals actually perform specific work tasks through various activities. Consider this same chart in terms of C-5 aircraft maintenance, shown in Table 2. The base-level focus on on-time departure reliability falls within the *operating objective* level, providing ready airplanes for the flying schedule. On the surface, this supports the strategic performance objectives of cargo and passenger delivery. These processes are, after all, at the core of the airlift mission. On-time departure reliability, as a measurement, only considers those airplanes scheduled to fly (departing).[19] TNMCM, on the other hand, is concerned with the categorization of aircraft status, and pertains to all possessed airplanes, regardless of whether or not there is an operational demand.[20] The takeaway here is that the study team's observations of the C-5 aircraft maintenance enterprise supported Dr Hammer's view presented in Table 1. The study team found that different levels of the C-5 maintenance hierarchy do in fact focus on different primary metrics.

Aligning Metrics

Although it may be common for different organizational levels to focus on different metrics, this split focus can be problematic for the enterprise when the pursuit of goals at the local level is not aligned to goals at the strategic level. That is, pursuit of better performance in one metric could result in suboptimal performance of higher level metrics. When this occurs, the metrics are not aligned. The study team utilized the following definition for aligned metrics:

> **Definition 1 - Aligned Metrics.** A set of metrics is said to be aligned if, with all other variables held constant, improvement in the lower level metric implies improvement of the higher level metrics.

	Leadership	Process Owner	Professionals
Enterprise Goals	High*	Low	Medium
Strategic Performance	High*	High	Medium
Operating Objectives	Medium	High*	Medium
Process Performance	Medium	High*	High
Activity Performance	Low		High*
* = primary accountability			

Table 1. Accountability and Attention[18]

	AMC/A4	MXG/CC	Technicians
Enterprise Goals – increase aircraft availability, reduce costs	High*	Medium	Low
Strategic Performance – deliver cargo and passengers accurately and on-time	High*	High	Medium
Operating Objectives – provide ready airplanes for the flying schedule	Medium	High*	Medium
Process Performance – isochronal inspections, unscheduled repair process	Medium	High*	High
Activity Performance – inspect and repair airplanes	Low	High	High*
* = primary accountability			

Table 2. Accountability and Attention for C-5 Aircraft Maintenance

For example, consider the priorities of a trucking company. The company is concerned with a higher level metric, known as a value measure, of increasing profit. The value measurement is in dollars. Shop managers at a truck maintenance facility use a lower level metric, known as a process measure, of reducing repair cycle time. By reducing the repair cycle time, the labor cost per truck is reduced, and each truck is returned to revenue-generating status sooner. All other variables held constant, reduced labor costs and greater numbers of operational trucks increase profit for the company. In this way, improving cycle time implies improvement in profit.[21] By Definition 1, these metrics are aligned.

Now consider the Air Force maintenance metrics of HSLDR rate and TNMCM rate. The base focus on departure reliability may have a direct effect on prioritizing unscheduled maintenance actions to best meet the flying schedule. This optimization can cause an airplane that is *hard broke* to be prioritized below another airplane in order to get the *less broke* airplane repaired more quickly and readied for the next flight. This decision, while supporting the objective of on-time departure reliability, may actually have a negative effect on the TNMCM rate. If, however, HSLDR and TNMCM were aligned, an improvement to HSLDR would imply an improvement to TNMCM. To investigate the alignment of the HSLDR, TNMCM, and AA metrics, the study team analyzed data from August 2004 through December 2006 for the 436 MXG at Dover Air Force Base (AFB). The 436 Maintenance Operations Squadron (MOS) analysis section provided the data for the HSLDR and TNMCM rates; the source for the AA rates was the Multi-Echelon Resource and Logistics Information Network.

Mathematically, metric alignment implies that two metrics are fairly strongly related. To test the correlation mathematically, the study team employed the correlation coefficient denoted by the symbol ρ (rho). The correlation coefficient is a number between -1 and 1 which measures the degree to which two variables are linearly related and is scaled such that $\rho > 0$ indicates a positive correlation between the variables. A value of $\rho = +1$ implies a perfect correlation with all ordered pairs (points) falling on a straight line with a positive slope. A value of $\rho = -1$ implies a perfect negative correlation with all points on a straight line with a negative slope.[22] For the purposes of this study, the study team partitioned the correlation coefficient values in the following manner:

- $|\rho| \leqslant 0.20$ implies a very weak correlation
- $0.20 < |\rho| \leqslant 0.50$ implies a weak correlation
- $0.50 < |\rho| \leqslant 0.80$ implies a moderate correlation
- $0.80 < |\rho| \leqslant 1.0$ implies a strong correlation

Figure 1 illustrates the relationship between the TNMCM rate and HSLDR rate.

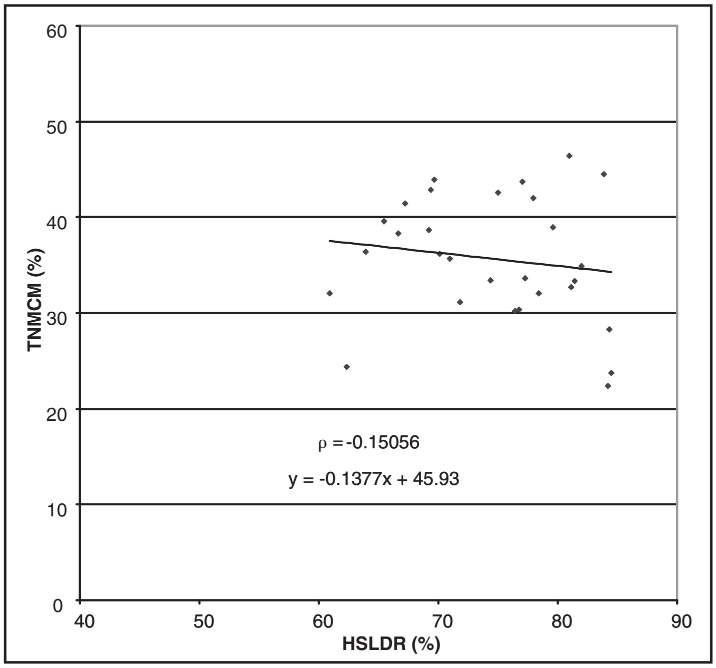


Figure 1. HSDLR and TNMCM Rates Scatter Plot for 436 MXG August 2004 to December 2006

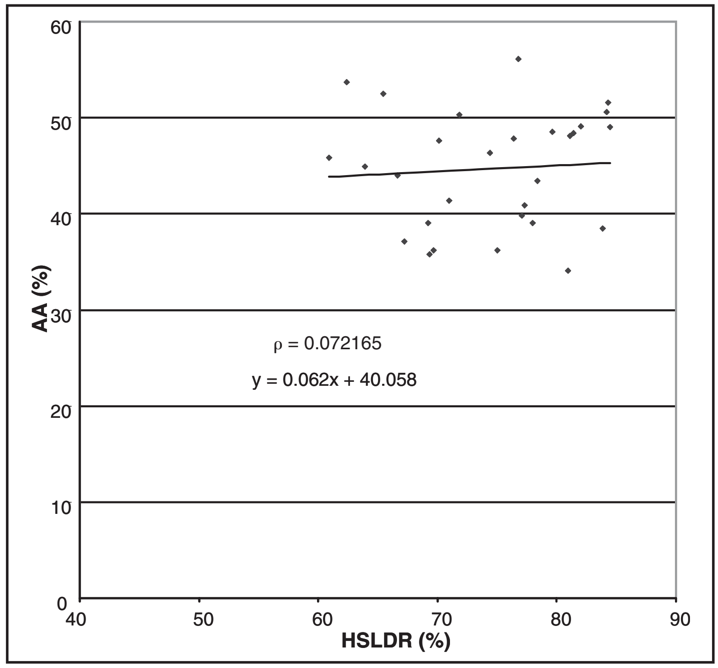


Figure 2. HSLDR and AA Rates Scatter Plot for 436 MXG August 2004 to December 2006

If the metrics were aligned, the graph should show evidence of a strong negative correlation. That is, as HSLDR increased, TNMCM would decrease and vice versa. In this case, the scatter plot reveals no definite relationship, appearing more like a *shotgun* spread. For comparison purposes, the least squares regression line for the data is drawn and the line equation is presented. A regression equation allows for the expression of a relationship between two or more variables algebraically. From Figure 1, the correlation coefficient between HSLDR and TNMCM is very weak, with ρ = -0.15056. Therefore, improvement of the HSLDR rate does not imply improvement of the TNMCM rate. By the study's definition, HSLDR and TNMCM were not aligned metrics.

Figure 2 illustrates the relationship between the HSLDR rate and AA rate, the primary metric at the MAJCOM A4 level. Again, the plot resembles a shotgun spread, and there is a very weak correlation coefficient with ρ = 0.072165. HSLDR and AA do not appear aligned according to the study's definition.

Figure 3 illustrates the relationship between the TNMCM and AA rates. Here, the scatter plot reveals a negative correlation. Likewise, the correlation coefficient indicates a moderate negative correlation with ρ = -0.77927. This evidence supports the idea that TNMCM and AA are aligned according to the study definition. As the TNMCM rate improves (decrease), the AA rate also tends to improve (increase). This result is not surprising since TNMCM and AA are a part of the same family of status-hour metrics.

In summary, Figures 1, 2, and 3 suggest that TNMCM and AA are aligned, and HSLDR is not aligned with either TNMCM or AA. As stated earlier, the MXG/CC's focus on HSLDR as their primary metric, not TNMCM and AA. Therefore, the MXG/CCs and their personnel make decisions about resources and day-to-day operations which impact HSLDR first. Since HSLDR is not aligned with TNMCM and AA, there is no guarantee that TNMCM or AA will improve as a result of the current operations.

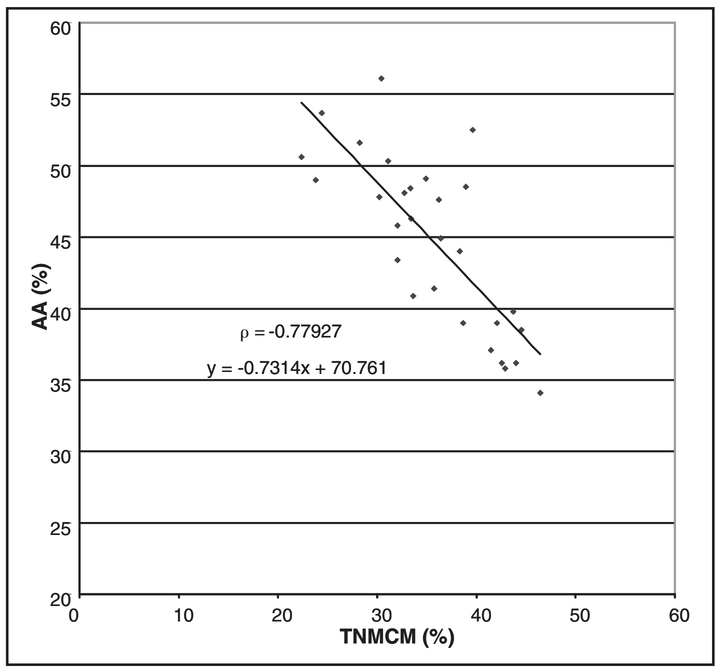


Figure 3. TNMCM and AA Rates Scatter Plot for 436th MXG August 2004 to December 2006

The MXG efforts, therefore, are not directly aimed at improving TNMCM rates when they are focusing on improving HSLDR rates.

Experimentation Using C-5 Maintenance Priority (MXP) Simulation

In order to test the impact to TNMCM rates of base-level HSLDR-centric maintenance decisionmaking, the AFLMA study team created a discrete event simulation using *Arena* simulation software. The simulation facilitated an analysis of how different maintenance operations could affect the HSLDR and TNMCM rates in a controlled environment. This analysis would be impractical to do in the real world. The following sections summarize the development and results of the C-5 maintenance priority (MXP) simulation.

MXP Problem Formulation and Objectives

The MXP model was designed to study the employment of different queuing prioritization policies and their effect on key maintenance performance metrics in the support of C-5 aircraft. These policies determine the order in which aircraft awaiting maintenance are processed. Field interviews conducted by the study team revealed that in order to improve HSLDR, the maintenance commanders gave priority to those aircraft that "have the best chance of being returned to a [fully mission capable] status in minimum time."[23] These *recovery maintenance* practices were utilized at both Travis AFB and Dover AFB for C-5 maintenance.[24] The MXP model labels this as the least maintenance (MX) policy and determines the priority of queued aircraft based on the remaining man-hours of repair. Thus, the aircraft with the fewest man-hours of repair remaining relative to other queued aircraft receives top priority when maintenance resources become available. Alternatively, the most MX policy gives priority to the aircraft with the most man-hours of repair remaining. The two remaining policies are first-in-first-out (FIFO) and last-in-first-out (LIFO). These queuing policies order aircraft according to their arrival. With FIFO, a newly arrived aircraft goes to the back of the queue. In a LIFO policy environment, a newly arrived aircraft goes to the front of the queue.

MXP Data Collection

Data for the MXP came from multiple sources. Aircraft arrival data was provided by the 436 MOS at Dover AFB for the period from January 2006 through March 2007. Manpower data was provided by the 436th Aircraft Maintenance Squadron for March and April 2007. Data for the possessed aircraft inventory, HSLDR rates, and TNMCM rates were provided by the 436 MOS for the fourth quarter fiscal year (FY) 2006. Data for the maintenance processes were taken from the Reliability and Maintainability Information System (REMIS) for fourth quarter FY 2006. The study team determined that these data sets were the most suitable given the availability of data.

MXP Assumptions

Two important assumptions were made in the formulation of the MXP simulation:

- TNMCS time was assumed to have no impact on the maintenance operations or the TNMCM rate. The impact of supply operations was assumed to be accounted for in the repair time data. The MXP does not model any TNMCS time.
- Unit possessed time for all aircraft was assumed to be constant and equal for the four maintenance policies modeled in the MXP simulation.

MXP Model Conceptualization

The MXP simulation modeled C-5 maintenance operations at Dover AFB. The simulation modeled 18 aircraft (the average number of possessed aircraft for Dover AFB in the fourth quarter FY 2006) that arrive at the base according to a daily arrival schedule with a fixed number of breaks. To achieve the desired arrival stream attributes within the *Arena* simulation framework, the MXP model employed three separate processes.

The first process created 18 C-5 aircraft entities at time zero. The entities then entered an arrival queue at a gate which opens according to the aircraft arrival schedule. Once opened, the gate allowed a single aircraft to proceed to the maintenance process before closing until the next arrival signal was received. The same 18 aircraft entities flowed from arrival process to the maintenance process before being recycled back to the arrival process. In this way, the model never had more than 18 aircraft in the system at one time.

The second process tracked the day of the week. A clock entity was created at time zero and thereafter stepped through the days of the week at 24-hour intervals. The simulation employed two schedules that depend on the day of the week cycle. The first was related to the maintenance process and defined how many manpower resources were available to perform maintenance on a given day. The second schedule governed the aircraft arrival pattern.

The final process related to aircraft arrivals determined when the gate should be opened allowing an aircraft *to arrive* and proceed to the maintenance process. These triggers were created according to a schedule derived from 15 months of aircraft arrival data at Dover AFB. The data defined day-specific discrete probability distributions of the number of aircraft arrivals. These distributions are given in Table 3.

The manpower resources and repair times required to complete the repairs were drawn from distributions based on the real-world data. The aircraft wait in the maintenance queue until resources are available for repair. Repairs are then completed in three phases.

The values in each row of Table 3 represent the probability of the particular number of arrivals (represented as 0 through 8 in the column headings) on that day of the week. Each row sums to one. These daily arrival distributions are the building blocks for a random aircraft arrival stream based on historic observations at Dover AFB. When all repairs are complete, the manpower resources are released to perform other repairs and the aircraft departs the base.

REMIS data was used to derive a discrete distribution of the number of personnel on a work crew associated with a repair action. Each repair action is assigned a randomly sized crew. Table 4 shows the crew size probability distribution used in the simulation. For example, there is a 0.519 probability that a repair action requires two maintenance personnel. When all repairs are complete, the manpower resources are released to perform other repairs and the aircraft departs the base. The data did not indicate any instances of crew sizes of seven or eight people during the timeframe of the data.

Figure 4 illustrates the overall view of the basic maintenance processes modeled in the MXP.

C-5 arrivals are triggered according to an arrival schedule. After arrival, aircraft require (seize) maintenance resources, maintenance actions are performed, and then manpower resources are released. This cycle is accomplished three times before returning the aircraft to the arrival queue.

In order to model the parallel and serial nature of aircraft maintenance actions, the study team adopted the repair bin methodology used by Balaban et al., in their mission capable rate (MCR) simulation model, which they demonstrated using the C-5 fleet.[25] In reality, certain repair actions are accomplished simultaneously with other repair actions. However, by regulation, some actions cannot be performed simultaneously with certain other maintenance actions. Balaban et al., modeled this parallel and serial operation by grouping repair actions for a given aircraft into three bins or buckets. Repairs within a given bin are performed simultaneously, but the bins are repaired serially. Thus, all repairs in bin one are completed before beginning bin two repairs. The repair time for each bin is the longest of the repair times contained in the bin.[26] The MXP model also used three bins. The first bin contained 65 percent of the total number of repair actions, the second bin contained 25 percent, and the third bin contained 10 percent. This is very similar to the probabilities used in the MCR model—60, 30, and 10 percent, respectively.[27]

MXP Model Validation

As previously stated, the least MX priority system most closely matched the recovery maintenance practices in place at both Dover AFB and Travis AFB. Therefore, the study team deemed the least MX model the best representation of the current, real-world process and considered this model the as-is model. The study team used the HSLDR rate in order to validate the MXP simulation with the real-world maintenance processes. After calibrating the MXP, the least MX model achieved an HSLDR rate of 0.821 with a 95 percent confidence interval that included the real-world HSLDR rate of 0.833 for the timeframe of the data. It is important to note that the model's intended use was not as a predictive model (given C-5 break rates, how many maintenance resources are required to satisfy a given AA rate?), but only to make a relative comparison between the four given prioritization policies. The model was not designed to determine HSLDR/TNMCM/MX backlog or to determine maintenance manning levels.

MXP Results and Conclusions

Table 5 summarizes the MXP simulation results for the four policies examined with respect to three metrics: HSLDR, estimated TNMCM (Est TNMCM), and Sum of MX in the queue (MX backlog). MX backlog covers the middle ground between the other two metrics—the prioritization policy determines which aircraft the maintenance group returns to mission capable status soonest while the remaining aircraft accrue TNMCM time. MX backlog is a measure of the ability of the maintenance system to generate all possessed aircraft if called upon to do so. An ideal policy is one that would produce a high LDR rate, a low TNMCM rate, and a low MX backlog. Table 5 summarizes the results for each policy with regard to these three metrics.

- Least MX. The least MX model was the baseline for comparison to the other MX prioritization policies. It most closely resembled the *as-is* process of recovery maintenance. The HSLDR achieved in the model was representative of the real-world HSLDR rate and was used to validate the model. Likewise, the Est TNMCM rate achieved matched the real-world value for the timeframe of the data. MX backlog for the least MX model was the largest for the four policies considered. The MX backlog measured the ability to improve the steady-state TNMCM rate. The higher the backlog, the harder it was for the MX system to improve from their steady state TNMCM. Higher backlog means longer aircraft generation time.
- Most MX. The most MX prioritization policy had the same LDR (statistically speaking, within a 95 percent confidence

Arrivals (AC)	0	1	2	3	4	5	6	7	8
Sunday	0.231	0.461	0.2	0.093	0.015	-	-	-	-
Monday	0.092	0.139	0.292	0.215	0.108	0.092	0.047	-	0.015
Tuesday	0.015	0.047	0.2	0.261	0.185	0.154	0.107	0.031	-
Wednesday	0.015	0.077	0.093	0.307	0.308	0.138	0.062	-	-
Thursday	-	0.062	0.107	0.216	0.338	0.185	0.092	-	-
Friday	0.077	0.077	0.138	0.293	0.184	0.185	0.031	0.015	-
Saturday	0.169	0.416	0.246	0.061	0.062	0.046	-	-	-

Table 3. Probability of Number of Aircraft Arrivals by Day of the Week

Crew Size (CS)	1	2	3	4	5	6	9
P(CS)	0.323	0.519	0.123	0.022	0.003	0.001	0.009

Table 4. Crew Size Probability

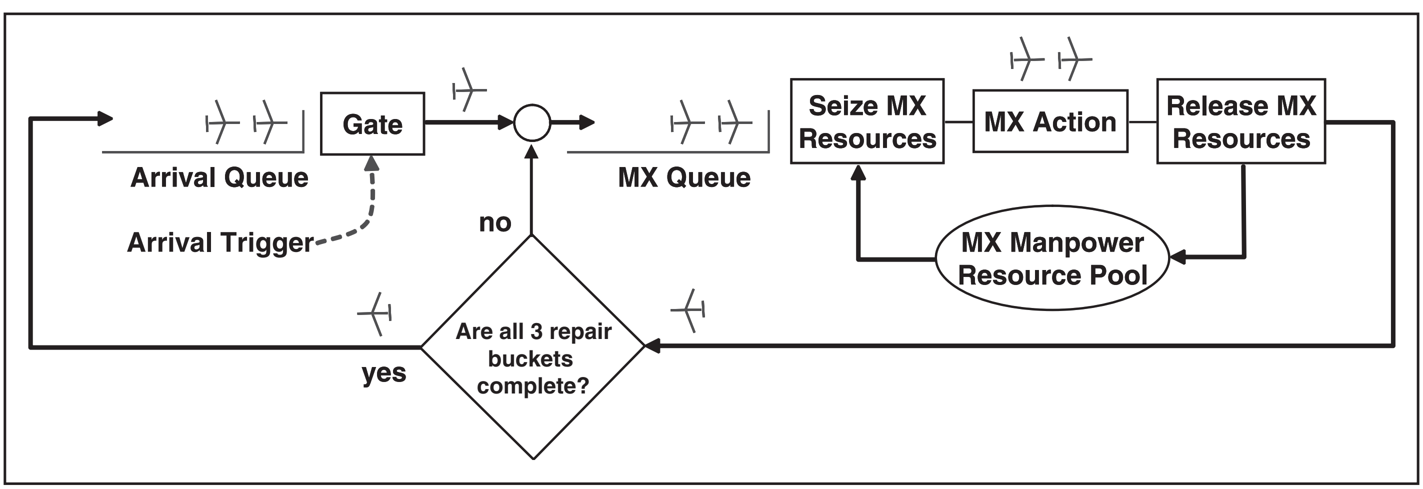


Figure 4. Maintenance Process as Modeled in the C-5 MXP Simulation

Policy	HSLDR	Est TNMCM	Mx Backlog
Least Mx	0.821	0.322	45K
Most Mx	0.816	0.305	23K
FIFO	0.764	0.307	20K
LIFO	0.735	0.393	30K

Table 5. Summary of MXP Results for Study Metrics

interval) as the least MX policy. Both the Est TNMCM and MX backlog improved over the least MX policy. This is intuitive because the most MX policy actively applies resources to the biggest maintenance jobs first. However, the variability from day to day increased significantly with this policy. This means that the predictability and stability for scheduling purposes suffered greatly.

- FIFO. The FIFO policy had a reduced LDR when compared to the least MX policy. However, the Est TNMCM improved, and was statistically the same as the Est TNMCM for the most MX policy (within 95 percent confidence intervals). The MX backlog was lower than the least MX policy as well.
- LIFO. The LIFO policy appeared to be the least attractive with regard to the key metrics. As compared to the least MX policy, it had a reduced LDR and increased Est TNMCM. It also had a reduced MX backlog when compared to the least MX policy but was the second worst of all the policies examined.

These results reveal several things about the prioritization policies and their impact to the LDR and TNMCM rates. First, LDR and TNMCM react differently depending on maintenance policy. The current policy in place (least MX) achieves a high LDR but has a mediocre estimated TNMCM when compared to the other policies, and the worst MX backlog, which indicates that it is very difficult to improve the TNMCM rate. It is possible to improve the TNMCM rate by changing the prioritization policy. However, the improved TNMCM would come at the cost of predictability and stability in day-to-day operations (as with most MX policy) and LDR, as is the case with the FIFO policy. The results of the simulation added support to the original hypothesis that HSLDR and TNMCM are not aligned metrics, but did not completely confirm it. While the current system can not be modeled perfectly, the simulation results did suggest that current maintenance policies do not ensure TNMCM improvement, but do improve LDR. It is safe to conclude that TNMCM and LDR are not necessarily aligned, complementary metrics.

Several personnel interviewed during the study team's site visits suggested that awareness exists of the just-described disconnect between enterprise goals (aircraft availability) and operating objectives. "There is a huge disconnect between AMC's focus on the availability of tails (airplanes) and our focus on on-time departure reliability."[28]

Consequently, while process owners are diligently focused on supporting the strategic performance objectives of delivering cargo and passengers, they are unable to simultaneously align their performance with the enterprise goal of increased aircraft availability.[29]

Maintenance Metrics at Delta Airlines

As a means of comparing business practices, the study team elected to compare Air Force maintenance metrics with those of a leading commercial organization, Delta Airlines. The team interviewed representatives from Delta Airlines' reliability program office. The study team was told the focus of Delta's reliability program is driven by what is termed as Delays and Cancellations (D&C).[30] These are unscheduled events that have an operational impact and require a mechanical dispatch. For each delay or cancellation, there is a direct, net consequence to Delta's revenue, so there is a high priority placed on diagnosing the cause.

Delta personnel identified nine main aircraft maintenance metrics used by Delta. These metrics are summarized in Table 6.[31] Note that technical dispatch reliability (TDR) includes all maintenance related to primary delays and cancellations, whereas mechanical dispatch reliability (MDR) includes only those primary events for which the reliability program is responsible. Repairs due to damage, *cannot duplicate* actions, maintenance carryovers, and maintenance errors (such as over-servicing) are not included in MDR. Dispatches are the term used for all of Delta's revenue flights.[32] Although there is not an explicit hierarchy, the first two metrics, TDR and MDR, are directly linked to the daily revenue-producing flights on Delta's schedule. These metrics track the volume of, and reasons behind, delays and cancellations for a revenue flight.

Maintenance carryovers are Delta Airlines' equivalent to delayed discrepancies in the Air Force. Maintenance carryovers are repairs that may be delayed (or carried over) to a more opportune time. Unscheduled aircraft out of service (UAOOS) measures the number of aircraft out of service due to an unscheduled event (such as a broken component). Delta measures UAOOS by counting the number of aircraft in this category three times per day (0900 hours, 1200 hours, and 1800 hours), and averaging that count over specified intervals.[33] Prioritization of repair is often given to aircraft that can be returned to service quickly, but the level of impact to fleet operations may be the driving factor.[34] As an example, a broken B-777 has a much bigger impact than a broken MD-88; the MD-88 fleet has many spares, while the B-777 does not.[35] The UAOOS metric is analogous to the Air Force TNMCM rate, though it is only focused on the unscheduled aircraft and is counted in whole aircraft rather than hours. Delta's primary metrics (those driven by delays and cancellations) are not measured to an objective standard (*met* or *not met*), instead, they *alert* when they exceed a control limit for 2 consecutive months.[36] Additionally, Delta personnel interviewed suggested that the metrics are driving desired behavior; this is supported by measured performance, as TDR averaged 97 percent fleet-wide at the time of the original study's publication.[37]

Delta has a very clear enterprise-level value measure—profit. This clear value measure lends itself well to metric definition at the operational level, which is why Delta focuses on the D&Cs. The D&Cs have a direct net effect on the revenue producing flights, which in turn has a direct impact on profit.

Value Metrics in the Mobility Air Forces

The MAF on the other hand, seems to have two competing enterprise-level value metrics.

- Strategic Readiness. AA and TNMCM rates measure the ability of the fleet to be fully mobilized at any given time

- Operational Effectiveness. HSLDR rates measure the ability of the fleet to meet the daily mission requirements.

Conventional wisdom argues that increased strategic readiness facilitates operational effectiveness—increased AA and decreased TNMCM should lead to increased HSLDR. However, as previously shown, there is a weak correlation between HSLDR and both AA and TNMCM. Again, these metrics are not aligned.

Conclusions

This article discussed the focus on different metrics to include HSLDR, TNMCM, and AA at varying levels of the Air Force maintenance enterprise. It also demonstrated that HSLDR is aligned with neither AA nor TNMCM, as there is only a weak correlation between them. Maintainers at the wing level work to support operational effectiveness; however, higher levels of Air Force supervision appear more focused on improving strategic readiness. This disconnect in priorities was determined to be a root cause of the C-5 TNMCM rate being below Air Force standards. This article does not advocate one metric over another. That choice is left for Air Force leadership to make. This article illustrates that, in this case, the primary metrics at varying levels of aircraft maintenance are not aligned and not complementary to one another.

If the Air Force's primary goal is to improve the C-5 fleet TNMCM rate, then priorities of the maintainers in the field must change. As the MXG leadership focuses on HSLDR performance, not TNMCM, the MXP simulation indicated that improving the TNMCM rate would require an increase in resources. Therefore, in order to improve the TNMCM rate without increased resources, the maintainers in the field must make TNMCM a priority. While it is impossible to model the current system perfectly, the results suggest that current maintenance policies do not ensure TNMCM improvement, but do improve HSLDR, which is the stated priority of the MXG leadership. Therefore, the study team recommended that MAJCOM A4 leadership and MXG leadership decide on a set of metrics that are better aligned toward the same goal.

This realignment of metrics must start at the highest levels of the MAF. The MAF should choose its value measure and create a set of metrics aligned with that measure. For example, if the MAF directs that operational effectiveness is its primary value, then metrics such as Tons of Cargo Moved or Million Ton Miles Moved over a given time period could be used as the value metric. Then it must be determined whether or not metrics at lower levels are aligned with the value metric. Once that is determined, all levels of maintenance leadership will have the same overarching priorities. Dr Hammer describes the entire view as *pulling it together* and lists three things to consider:

- Deciding what to measure is a science
- Deciding how to measure is an art
- Using measures is a process

Recommendations

- If improving C-5 TNMCM rates is the goal, all levels of maintenance leadership must make improving TNMCM rates a priority.
- AMC should determine its priorities between operational effectiveness and strategic readiness, and determine metrics aligned with these priorities.
- Conduct a study to determine whether or not increased AA is correlated with increased operational effectiveness in million ton miles or another pertinent metric. The answer to this

Metric	Formula
Mechanical Dispatch Reliability (MDR)	$100 - \left(\left(\frac{\text{Delays + Cancellations}}{\text{Revenue Departures}}\right) \times 100\right)$
Technical Dispatch Reliability (TDR)	$100 - \left(\left(\frac{\text{Technical Issues}}{\text{Revenue Departures}}\right) \times 100\right)$ Where technical issues include dispatches for mechanical, process, policy, and paperwork issues associated with delays and cancellations.
Unscheduled Aircraft Out of Service (UAOOS) Count	Number of Unscheduled Aircraft Out of Service
In-Flight Shutdown Rate (IFSDR)	$\frac{(\text{Total Inflight Shutdowns x 1,000})}{\text{Total Engine Hours}}$
Maintenance Carryovers (MCO) Count	Number of Maintenance Carryovers
MEL Count	Number of Restricted Items
Unscheduled Removal Rate (Used for the Engines and APUs)	$\frac{(\text{Total Unscheduled Removals x 1,000})}{\text{Total Hours}}$
Pilot Reports (PIREPS)	$\left(\frac{\text{Pilot Reports x 1,000}}{\text{Total Flying Hours}}\right)$
Flight Exception Rate	Number of Diversions, Air Turn Backs and Rejected Takeoffs for Mechanical Reasons

Table 6. Delta Airlines Maintenance Metrics

question will help determine the applicability of AA towards measuring operational effectiveness.

- AMC/A4 develop simpler, more concrete maintenance metrics that are easily countable and give an indication that operational effectiveness and or strategic readiness is going to be affected.

As previously mentioned, the metrics analysis, modeling, and simulation described in this article was developed as part of the larger *C-5 TNMCM Study II*. This is the second in a series of articles related to that study. The entire study can be found at the Defense Technical Information Center (DTIC) Private Scientific and Technical Information Network (STINET) Website at https://dtic-stinet.dtic.mil/.

Notes

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…my own view is that if Saint George's first priority with tackling dragons had been force protection, I don't think he would now be the patron saint of England.

—Air Vice Marshal Tony Mason, RAF

Man does not live by words alone, despite the fact that sometimes he has to eat them.

—William Broderick Crawford

Never doubt that you can change history. You already have.

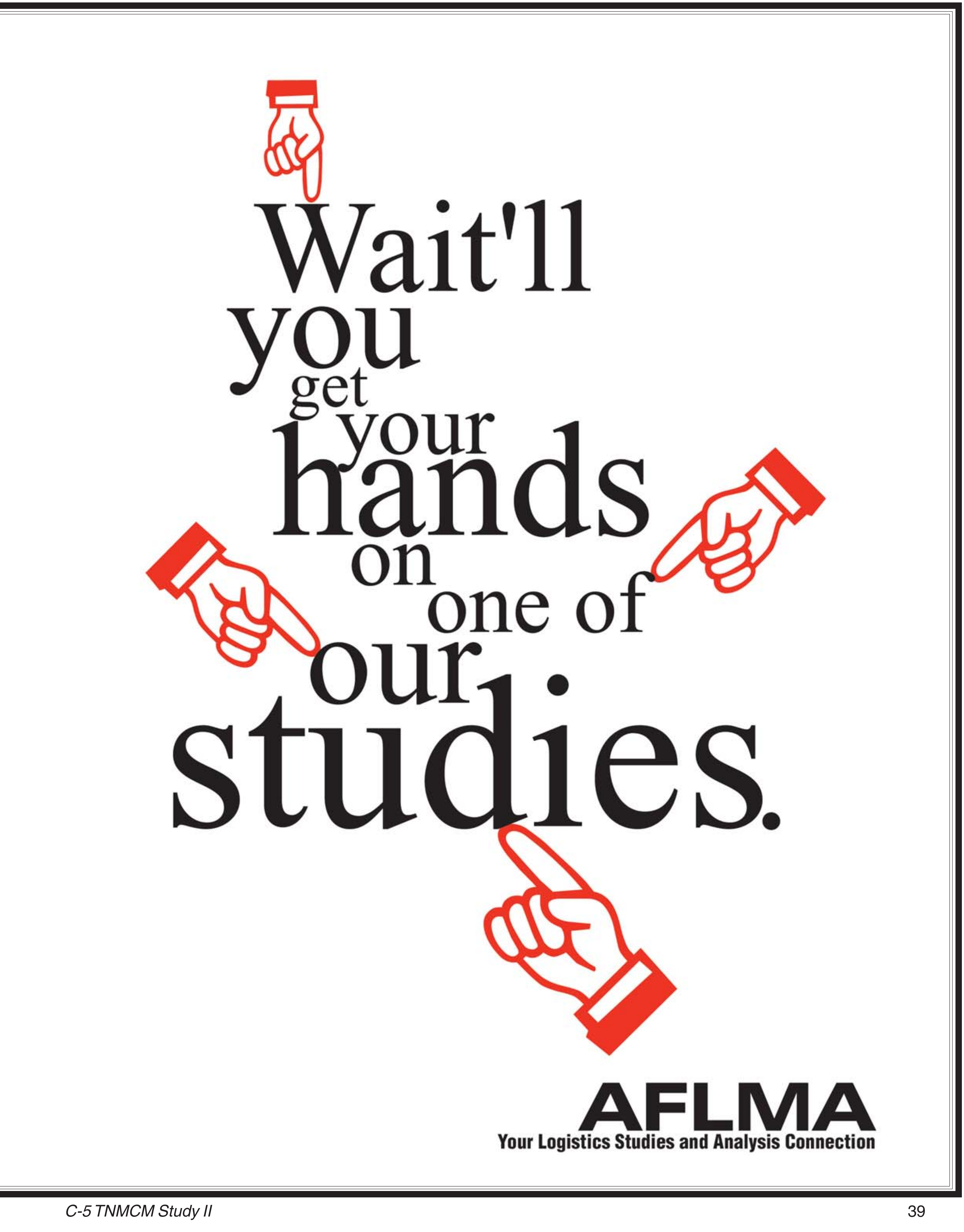
—Marge Piercy

Planning is everything—plans are nothing.

—Field Marshal Helmuth von Moltke

I said to myself, I have things in my head that are not like what anyone has taught me—shapes and ideas so near to me—so natural to my way of being and thinking that it hasn't occurred to me to put them down. I decided to start anew, to strip away what I had been taught.

—Georgia O'Keeffe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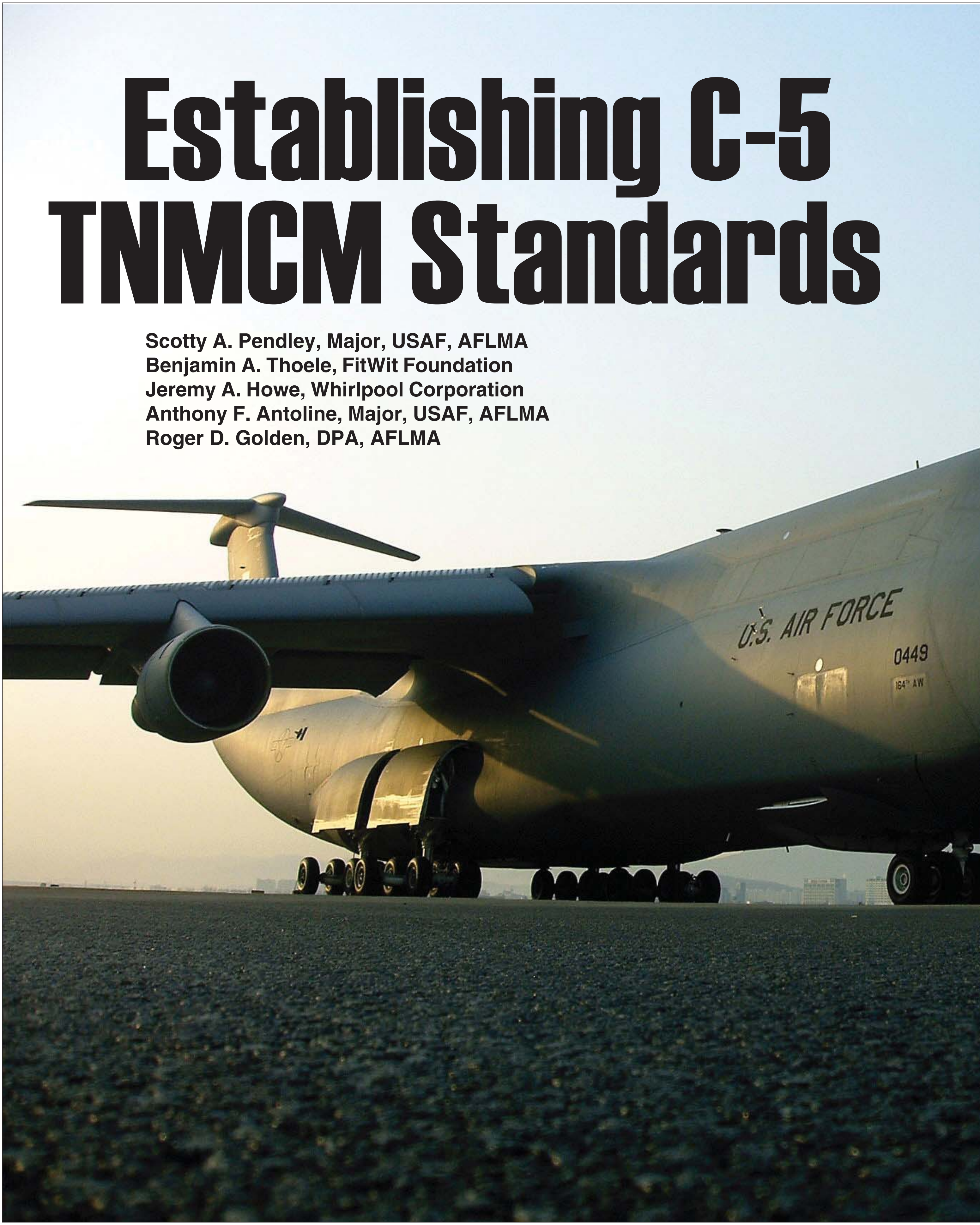
Establishing C-5 TNMCM Standards

Scotty A. Pendley, Major, USAF, AFLMA
Benjamin A. Thoele, FitWit Foundation
Jeremy A. Howe, Whirlpool Corporation
Anthony F. Antoline, Major, USAF, AFLMA
Roger D. Golden, DPA, AFLMA



The process for calculating and establishing Air Force-level TNMCM standards is not well known across the Air Force and not equally applied across the total force. Also, the process currently in use does not produce realistic, capability-based metrics to drive supportable operational decisions.

Introduction

This article details the process for calculating and establishing Air Force aircraft total not mission capable maintenance (TNMCM) standards. It is impossible to discuss the TNMCM rates and standards without including discussions of the mission capable (MC) and the total not mission capable supply (TNMCS) rates and standards. These three rates are dependent upon one another. Because the rates are percentages of total unit-possessed time, one rate cannot increase or decrease without impacting the other two. The Air Force standards applied to these metrics are interrelated as well. As discussed in this article, the TNMCM and TNMCS standards depend on the MC standard. Thus, the formulation of the MC standard is the foundation for the TNMCS and TNMCM standards.

The 2003 CORONA directed that Air Force-wide standards for MC, TNMCM, and TNMCS be established. While directed toward TNMCM, the research detailed in this article also revealed that the MC standard is the foundation for calculating the other two metric standards. As the process exists currently, the Air Force MC standards are based on requirements which are determined in one of three ways:

- The flying hour or flying schedule requirement
- Contract logistics support (CLS) contract
- Another requirement based on major command (MAJCOM) input determined by the designed operational capability (DOC) statement, readiness study, or any operational requirement the MAJCOM may use

In the case of the Air Force's C-5 Galaxy, Air Mobility Command (AMC) provides the active duty fleet MC standard to the Air Staff based on the *Mobility Requirements Study* (MRS). However, the standard is not actually calculated in the MRS, it is an assumption used in the MRS.

This is not the case for the separate Air Force Reserve Command (AFRC) and Air National Guard (ANG) fleet C-5 MC standards. Those two values are calculated at the Air Staff level. The AFRC MC standard is calculated from utilization rate, attrition, turn pattern, annual fly days, spares, aircraft held down for scheduled maintenance, and primary aerospace vehicles authorized. The ANG MC standard equation uses variables portraying daily operations and maintenance (O&M) flying hours, aircraft taskings per flying day over and

Article Highlights

There are numerous implications for the complex, seemingly disjointed standards methodology that are problematic for the Air Force at the strategic, operational, and tactical levels.

At the request of the Air Force Materiel Command Director of Logistics, AFLMA conducted an analysis in 2006-2007 of total not mission capable maintenance (TNMCM) performance with the C-5 Galaxy aircraft as the focus. The *C-5 TNMCM Study II* included five objectives. One of those objectives was to analyze the process for calculating and establishing TNMCM standards. This article details the analysis conducted in support of that particular study objective.

It is important to recognize that any discussion of TNMCM rates and standards must also include discussions of the mission capable (MC) and the total not mission capable supply (TNMCS) rates and standards. These three rates are dependent upon one another. Because the rates are percentages of total unit-possessed time, one rate cannot increase or decrease without impacting the other two. The Air Force standards applied to these metrics are interrelated as well. As the authors point out, the TNMCM and TNMCS standards depend on the MC standard. Thus, the formulation of the MC standard is the foundation for the TNMCS and TNMCM standards.

The research demonstrates that the process for calculating and establishing Air Force-level TNMCM standards is not well known across the Air Force and not equally applied across the total force. Also, the process currently in use does not produce realistic, capability-based metrics to drive supportable operational decisions.

The authors conclude by recommending that a repeatable methodology be developed to compute the TNMCM standard so that it:

- Reflects day-to-day minimum operational requirements
- Adjusts to fully mobilized force capabilities and surge mobility requirements
- Accounts for historic capabilities and fleet resources

above O&M flying, average number of aircraft required for standard flying operations each day, required daily spares, and the forecasted number of unit possessed aircraft over the year.

Background

At the request of the Air Force Materiel Command Director of Logistics (AFMC/A4), an AFLMA study team conducted an analysis in 2006-2007 of TNMCM performance with the C-5 aircraft as the focus. The *C-5 TNMCM Study II* included five objectives. One of those objectives was to analyze the process for calculating and establishing aircraft TNMCM standards. This article details the analysis conducted in support of that particular study objective.

Maintenance Metric Definitions

Air Force Instruction (AFI) 21-101, *Aircraft Equipment and Maintenance Management,* defines the MC, TNMCS, and TNMCM metrics and their uses. For additional insight on the use of these metrics see *Metrics Handbook for Maintenance Leaders*.

Mission Capable (MC) Rate

Though a lagging indicator, the MC rate is perhaps the best known yardstick for measuring a unit's performance. It is the percentage of possessed hours for aircraft that are fully mission capable (FMC) or partially mission capable (PMC) for specific measurement periods (such as monthly or annually).[1]

$$\text{MC (\%)} = \frac{\text{FMC Hours} + \text{PMC Hours}}{\text{Possessed Hours}} \times 100\%$$

Total Not Mission Capable Maintenance (TNMCM) Rate

Though a lagging indicator, the TNMCM rate is perhaps the most common and useful metric for determining if maintenance is being performed quickly and accurately. It is the average percentage of possessed aircraft (calculated monthly or annually) that are unable to meet primary assigned missions for maintenance reasons (excluding aircraft in *B-Type* possession identifier code status). Any aircraft that is unable to meet any of its wartime missions is considered not mission capable. The TNMCM is the amount of time aircraft are in NMCM plus not mission capable both (NMCB) status.[2]

$$\text{TNMCM (\%)} = \frac{\text{NMCM Hrs} + \text{NMCB Hrs}}{\text{Possessed Hours}} \times 100\%$$

Total Not Mission Capable Supply (TNMCS) Rate

Though this lagging metric may seem a logistics readiness squadron responsibility because it is principally driven by availability of spare parts, it is often directly indicative of maintenance practices. For instance, maintenance can keep the rate lower by consolidating feasible cannibalization actions to as few aircraft as practical. This monthly (annual) metric is the average percentage of possessed aircraft that are unable to meet primary missions for supply reasons. The TNMCS rate is the time aircraft are in not mission capable supply (NMCS) plus not mission capable both maintenance and supply (NMCB) status. TNMCS is based on the number of airframes out for mission capable (MICAP) parts that prevent the airframes from performing their mission (NMCS is not the number of parts that are MICAP).[3]

$$\text{TNMCS (\%)} = \frac{\text{NMCS Hrs} + \text{NMCB Hrs}}{\text{Possessed Hours}} \times 100\%$$

Fiscal Year (FY) 2007 C-5 Fleet Standards and Standards Calculations

As previously mentioned, during a 2003 CORONA, the Air Force Chief of Staff (CSAF) directed the establishment of Air Force-wide standards for the MC, TNMCS, and TNMCM metrics. Headquarters (HQ) Air Force Instalations and Logistics (now AF/A4) was named the office of primary responsibility (OPR). Their charter was to develop Air Force standards rooted in operational requirements and resources dedicated to each weapon system or mission design series (MDS). They subsequently developed calculation methodologies for calculating MC, TNMCS, and TNMCM standards. However, as of the time of the original study research, the study team found no official publication documenting the methodology for calculating these maintenance metric standards. Consequently, OPRs at the HQ Air Force and MAJCOM levels provided the study team with the definitions for the calculation methodologies that produced the C-5 fleet maintenance standards used in FY 2007. Table 1 summarizes the 2007 C-5 standard percentage rates for the MC, TNMCS and TNMCM metrics. An explanation of each method for deriving the standards follows.

MC Standard

The MC standard provides the foundation for calculating the other maintenance metric standards. According to HQ Air Force, Directorate of Maintenance, Weapons Systems Division, Sustainment Branch (AF/A4MY) personnel, the MC standards are based on requirements. The MC standard represents the percentage of MC aircraft required at the beginning of each flying day. That requirement is determined by one of the following three ways:[5]

- The flying hour or flying schedule requirement, calculated using Equation 1, 2, or 3.
- Contract logistics support (CLS) contract.
- Some other requirement based on MAJCOM input. That input can be a DOC statement, readiness study, or any operational requirement the MAJCOM may use.

The Air Reserve Component (ARC), a composite of both ANG and AFRC, MC standard is based on the number of aircraft committed to the flying schedule. However, the ANG flying commitment is based on O&M flying hours, transportation working capital fund (TWCF) hours, and the number of operations alert committed aircraft per flying day. Also included is the daily spares requirement. This commitment in aircraft is divided by the forecasted possessed aircraft to determine the MC requirement.[6]

Each year, AF/A4MY personnel request input from AMC for the MC standard. AMC determines the MC rate necessary to meet their airlift requirement and then gives their desired MC rate to Air Staff. Air Staff then uses this rate as the MC standard. This process is currently used to determine the active duty MC standards for the C-17, C-5, C130, KC-10, and KC-135 airframes.[7] These MC standards are based solely on AMC's input. AF/A4MY personnel do not calculate the MC standard for any of the above listed active duty fleets.

Article Highlights

Article Acronyms

AA – Aircraft Availability
AAT – Aircraft Availability Target
AC – Aircraft
ACC – Air Combat Command
AE – Aeromedical Evacuation
AFB – Air Force Base
AFI – Air Force Instruction
AFLMA – Air Force Logistics Management Agency
AFMC – Air Force Materiel Command
AFRC – Air Force Reserve Command
AFSO21 – Air Force Smart Operations for the 21st Century
AMC – Air Mobility Command
ANG – Air National Guard
BE – Business Effort
CLS – Contract Logistics Support
CONOPS – Concept of Operations
CSAF – Chief of Staff, United States Air Force
DOC – Designed Operational Capability
DoD – Department of Defense
FMC – Fully Mission Capable
FY – Fiscal Year
GAO – Government Accountability Office
HQ – Headquarters
LMI – Logistics Management Institute
LRS – Logistics Readiness Squadron
MAJCOM – Major Command
MC – Mission Capable
MCS – Mobility Capabilities Study
MDS – Mission Design Series
MERLIN – Multi-Echelon Resource and Logistics Information Network
MICAP – Mission Capable
MRS – Mobility Requirements Study
NMCB – Not Mission Capable Both
NMCM – Not Mission Capable Maintenance
NMCS – Not Mission Capable Supply
O&M – Operations and Maintenance
OPR – Office of Primary Responsibility
PAA – Possessed Aircraft Authorized
PMC – Partially Mission Capable
REMIS – Reliability and Maintainability Information System
RERP – Reliability Enhancement and Re-Engining Program
TNMCM – Total Not Mission Capable Maintenance
TNMCS – Total Not Mission Capable Supply
TWCF – Transportation Working Capital Fund
UTE - Utilization

		Active Duty	ARC	*AFRC*	*ANG*
MC	**Standard**	75	50	*50*	*47*
	Method	*MAJCOM Input*	*Equation 3*	*Equation 1*	*Equation 2*
TNMCS	**Standard**	8	8		
	Method	*Equation 4*	*Equation 4*		
TNMCM	**Standard**	24	50		
	Method	*Equation 6*	*Equation 6*		

Table 1. FY 2007 C-5 Maintenance Standards and Calculation Methodologies[4]

The three MC standard requirement algorithms are detailed in Equations 1, 2, and 3. Equation 1 is typically used with active duty aircraft fleets.

$$MC_{Std} = \left[\frac{12 \times UTE}{(1 - Attrition) \times (Turn\ Pattern) \times (Fly\ Days)}\right] + \left[\frac{Spares + MC_{SchdMX}}{PAA}\right]$$

Equation 1. MC Standard[8]

Where:

MC_{std} is MC Standard.

UTE is the sortie utilization rate, which is the number of sorties required to fly each month by authorized aircraft. 12 x *UTE* yields the annual sorties required to meet the flying hour program (FHP).

Attrition is the annual attrition rate of sorties lost due to operations, maintenance, and other considerations such as weather. Dividing by (1-*Attrition*) yields the sorties required to be scheduled to account for attrition.

Turn pattern, or turn rate, is the total number of sorties scheduled divided by the number of *first go* sorties. For example: a unit schedules 100 sorties during the week and 60 of them occur on the *first go* of the day. The turn rate would be 100/60 = 1.67. Dividing by *turn pattern* yields the number of front-line flyers. Dividing by the number of *fly days* yields the number of front-line flyers per day.

Fly Days = 232. This figure assumes 244 *working days* minus 12 *goal days*.

Spares, or front line spares, is the number of scheduled spare aircraft for the *first go*.

MC_{SchdMX} is the average number of aircraft per squadron held down on each flying day for scheduled maintenance including delayed discrepancies, health of the fleet management, washes, and so forth.

Spares + MC_{SchdMX} is expressed as a percentage of squadron possessed aircraft authorized (PAA).

PAA is the number of aircraft authorized for a unit to perform its operational missions.[9]

Equation 2 is the algorithm used by the ANG.

$$MC_{ANG} = \left[\frac{\lceil AC_{O\&M} + AC_{TWCF/BE/AE} + AC_{Ops} + Spares \rceil}{AC_{Forecast}}\right]$$

Equation 2. MC Standard for ANG[10]

Where:

$AC_{O\&M}$ is the average number of committed aircraft based on the O&M requirements per flying day.

$AC_{TWCF/BE/AE}$ is the number of aircraft required for taskings per flying day that the ANG supports above its O&M flying (such as TWCF, aeromedical evacuation (AE), business effort [BE]).

AC_{Ops} is the average number of aircraft required for standard flying operations per flying day.

Spares is the same as in Equation 1, but is reported as the number of aircraft per flying day.

$AC_{Forecast}$ is the number of aircraft that are expected to be unit possessed over the year based on depot maintenance schedules and other considerations.

$\lceil x \rceil$ shown in the numerator of Equation 2 denotes the smallest integer greater than or equal to *x*. This function rounds any decimal value up to the next whole number. The ceiling function is used in order to speak in terms of whole aircraft.

Equation 3 is utilized to calculate the MC standard for the composite ARC portion of an aircraft fleet.

$$MC_{ARC} = \frac{(MC_{AFRC} \times PAA_{AFRC}) + (MC_{ANG} \times PAA_{ANG})}{PAA_{AFRC} + PAA_{ANG}}$$

Equation 3. MC Standard for ARC Fleet[11]

The MC standard for the AFRC (MC_{AFRC}) fleet is calculated using the standard MC equation given in Equation 1. For simplicity, the result of this formula is rounded to the nearest tenth.

TNMCS Standard

Active duty and ARC fleets use the same methodology for TNMCS once the MC standard is established. This calculation is shown in Equation 4. Note that separate TNMCS standards for AFRC and ANG are not calculated.

$$TNMCS_{Std} = 1 - AAT$$

Equation 4. TNMCS Standard[12]

The aircraft availability target (AAT), ties the TNMCS standard to the funding and requirements for spare parts that are calculated in the Requirements Management System.[13] It assumes the supply pipeline and spare safety levels are fully funded. The *AAT* for the C-5 has been at 92 since the beginning of the maintenance standard development. This yields a TNMCS standard of 8 which is applied to both ARC components.

Equation 5 defines the aircraft availability target calculation.

$$AAT = Required\ MC + NMCM_{3\ year\ historical}$$

Equation 5. AAT Calculation[14]

Required MC is determined the same way that the Air Force active duty MC standard is determined.[15]

$NMCM_{3\ year\ historical}$ is the 3-year historical average of the NMCM rate for the particular MDS under consideration.

It is important to note that the maintenance metrics standards established for FY07 (Table 1) used the FY05 calculated AATs.

This is because the C-5 parts on the shelf in FY07 were based on the FY05 AATs.[16] As just mentioned, the FY05 AAT for the C-5 fleet was 0.92. The Logistics Management Institute (LMI) updated the AAT-setting methodology in 2006 to include computations for *Required MC* and NMCM rates for both day-to-day operations and predeployment.[17]

TNMCM Standard

Active duty and ARC fleets use the same methodology for TNMCM once the respective MC standard is established. This calculation is shown in Equation 6. Note that separate TNMCM standards for AFRC and ANG are not calculated.

$$TNMCM_{Std} = 1 - \left(MC_{Std} + TNMCS_{Std}\right) + NMCB_{3\ yr\ historical}$$

Equation 6. TNMCM Standard[18]

$NMCB_{3\ yr\ historical}$ is the average NMCB rate over the previous 3 years. The data used for the FY07 calculation came from the Reliability and Maintainability Information System (REMIS); the average NMCB for FY04, FY05, and FY06 equaled 0.07.[19]

Standards Calculation Examples

This section applies the above formulas to the real-world data that produced the metric standards in Table 1.

FY07 Active Duty C-5 Fleet

MC Standard (MAJCOM Input):

AMC stated that the MC standard is 0.75 (75 percent) based on an operational requirement used in the Mobility Requirements Study (MRS) 2005 (MRS-05).

TNMCS Standard (Equation 4):

$$TNMCS_{Std} = 1 - AAT = 1 - 0.92 = 0.08$$

TNMCM Standard (Equation 6):

$$\begin{aligned} TNMCM_{Std} &= 1 - \left(MC_{Std} + TNMCS_{Std}\right) + NMCB_{3\ yr\ historical} \\ &= 1 - (0.75 + 0.08) + 0.07 \\ &= 0.24 \end{aligned}$$

FY07 ARC C-5 Fleet

The data required to calculate the ARC standards for FY07 is given in Table 2. AFRC and ANG provided the data in response to the FY07 Air Force Standards Data Call.

The PAA numbers the commands provided were 32 for the AFRC and 16 for the ANG. These values reflected the PAA before the PAA was adjusted to accommodate units recently gaining C-5s. To compute the AFRC MC standard, AF/A4MY used the PAA based on AFRC input, which was 32. However, for the weights in determining the composite ARC MC standard, AF/A4MY used the PAAs for FY07, which included the additions for the gaining units. These values are 40 for AFRC and 29 for ANG.

AFRC MC Standard (Equation 1):

$$MC_{AFRC} = \left[\frac{12 \times UTE}{(1 - Attrition) \times (Turn\ Pattern) \times (Fly\ Days)}\right] + \left[\frac{Spares + MC_{SchdMX}}{PAA}\right]$$

$$MC_{AFRC} = \left[\frac{12 \times 8.5}{(1 - 0.23) \times (1.3) \times (232)}\right] + \left[\frac{2 + 0}{32}\right] = \left[\frac{102}{232.232}\right] + \left[\frac{2}{32}\right] = 0.502$$

ANG MC Standard (Equation 2):

$$\begin{aligned} MC_{ANG} &= \left[\frac{\left[AC_{O\&M} + AC_{TWCF/BE/AE} + AC_{Ops} + Spares\right]}{AC_{Forecast}}\right] \\ &= \left[\frac{\left[3.84 + 1.19 + 0.45 + 1.3\right]}{15}\right] \\ &= \left[\frac{\left[6.78\right]}{15}\right] = \left[\frac{7}{15}\right] = 0.47 \end{aligned}$$

ARC MC Standard (Equation 3):

$$\begin{aligned} MC_{ARC} &= \frac{(MC_{AFRC} \times PAA_{AFRC}) + (MC_{ANG} \times PAA_{ANG})}{PAA_{AFRC} + PAA_{ANG}} \\ &= \frac{(0.50 \times 40) + (0.47 \times 27)}{67} = 0.488 \approx 0.50 \end{aligned}$$

TNMCS Standard (Equation 4):

$$TNMCS_{Std} = 1 - AAT = 1 - 0.92 = 0.08$$

TNMCM Standard (Equation 6):

$$\begin{aligned} TNMCM_{Std} &= 1 - \left(MC_{Std} + TNMCS_{Std}\right) + NMCB_{3\ yr\ historical} \\ &= 1 - (0.50 + 0.08) + 0.08 \\ &= 0.50 \end{aligned}$$

Of note is the fact that the 3-year average NMCB was actually 0.166 (based on Multi-Echelon Resource and Logistics Information Network [MERLIN] data). AF/A4MY capped the NMCB at 0.08 because the historical NMCB cannot theoretically exceed the TNMCS. Recall that TNMCS is the sum of NMCS and NMCB; therefore, NMCB *should be* less than or equal to TNMCS.[21] The TNMCS standard is established as a resourced goal and the Air Force is trying to achieve a balance in the maintenance standards.[22]

AMC Determination of the C-5 MC Operational Requirement

According to AF/A4MY and AMC/A4MXA, AMC provides Air Staff with the value for the MC standard for the active duty fleet. This standard has been 75 percent since 2003, the year that Air Force-wide standards were implemented.[23] AMC/A4MXA stated that the value of 75 percent was based on the MRS.[24] According to the AMC/A9 office, every major mobility study including the MRS (1992), the *MRS Bottom-Up Review Update* (1995), MRS-05 (2000), and the *Mobility Capabilities Study* (2005), has used 75 percent as the C-5 MC rate standard to

	PAA Command Input	PAA (FY07 Actual)	UTE	Attrition	Turn Pattern	Fly Days	Spares	MC for Sched Mx
AFRC	32	40	8.5	0.23	1.3	232	2	0

	PAA Command Input	PAA (FY07 Actual)	O&M AC/day	TWCF,BE, AE AC/day	Spares/ day	Ops AC/day	Possessed AC Forecast
ANG	16	27	3.84	1.19	1.3	0.45	15

Table 2. Data for AFRC and ANG MC Standard Calculations[20]

determine the capability of the C-5 fleet to support the mobility forces.[25]

Examination of the MRS-05 revealed the MRS-05 did not calculate an MC standard; the MRS-05 assumed an MC rate of 76 percent for a fleet in which all C-5s have had the Reliability Enhancement and Re-Engining Program (RERP) modifications. The MRS-05 explains that the use of 76 percent MC rate is because of expected RERP improvements. The study also assumes a 65 percent MC rate for aircraft that have not received the RERP improvements.[26] The director of the AMC office of Analysis, Assessments, and Lessons Learned (AMC/A9) concurred that the C-5 MC standard is not based on any formal calculation or analysis, and stated that the original estimate (circa 1990) of a 75 percent MC rate was deemed "a prudent objective" for planning purposes.[27] AMC/A9 stated that the 75 percent MC rate assumes a fully mobilized total force to support C-5 maintenance operations.[28]

In summary, the FY07 MC, TNMCS, and TNMCM standards for the C-5 active duty fleet are based on the assumption that the C-5 fleet can achieve a 75 percent MC rate with the entire fleet receiving RERP upgrades or a fully mobilized total force to support maintenance operations.

Implications of the Methodology

There are numerous implications of this complex, seemingly disjointed standards methodology that are problematic for Air Force members at the strategic, operational, and tactical levels. First, Equation 1, in its present state, is more appropriate for fighter aircraft than mobility aircraft.[29] For example, the *Turn Pattern* and MC_{SchdMX} variables are reflective of fighter aircraft flying schedules. Mobility aircraft are less often *turned* on the same flying day, and mobility aircraft units, having a relatively small number of PAA, often have less opportunity to hold aircraft down for fleet health purposes. Consequently, this is a contributing factor to AF/A4MY's rationale of using AMC's input to determine active duty standards. The study team concluded that if Equation 1 is not appropriate for heavy aircraft, then it should not be used as a foundation for the MC standard. The variables used to measure performance need to accurately reflect the relevant process.

An additional issue is a lack of consistency across the total force components. The active duty component uses AMC input to determine the MC standard, but the ARC uses calculation methodology. Moreover, in addition to the planning objective used to determine the active duty maintenance standards and the calculations used to determine the ARC standards, the total force components, including the ANG, have maintenance metric goals. These goals are separate from the Air Force standards and are calculated differently. Within the ANG, units report their performance with regard to the ANG goals, and not necessarily the ARC metric standards. While the functional mission differences between fighter and mobility aircraft may justify distinct calculation methodologies, inconsistencies within a given airframe (for example, the C-5) are less easily supported. Consistency, in fact, is identified by AFI 21-101 as one of four important characteristics of a metric. These four characteristics are:

- Accurate and useful for decisionmaking
- Consistent and clearly linked to goals or standards
- Clearly understood and communicated
- Based on a measurable, well-defined process[30]

The fourth characteristic mentioned above highlights another concern given the current methodology for calculating the C-5 standards. Fundamentally, the process is not rigidly followed as part of formal policy; rather, the practice of establishing standards involves numerous deviations, discussed at length earlier in this article (active duty MC input, AAT from FY05, ANG goals). Simply stated, there was no complete, published, defined process. In April 2003, the United States Government Accountability Office (GAO) discussed these same issues in a report addressing aircraft availability goals across the Department of Defense (DoD).[31] The GAO found that all branches of military Service fail to clearly define the standards computation process for aircraft maintenance metrics.

The following selected comments were taken from the GAO report's executive summary:

> Despite their importance, DoD does not have a clear and defined process for setting aircraft availability goals. The goal-setting process is largely undefined and undocumented, and there is widespread uncertainty among the military Services over how the goals were established, who is responsible for setting them, and the continuing adequacy of MC and FMC goals as measures of aircraft availability. DoD guidance does not define the availability goals that the Services must establish or require any objective methodology for setting them. Nor does it require the Services to identify one office as the coordinating agent for goal setting or to document the basis for the goals chosen.[32]

Speaking in terms of consequence, the GAO suggested that the "lack of documentation in setting the goals ultimately obscures basic perceptions of readiness and operational effectiveness."[33] Additionally, the report documented several findings specifically relevant to establishing standards for the Air Force. These findings included:

- Air Force officials told [the GAO] that they generally try to keep the goals high because it is difficult to stop the goals from dropping further once they begin to be lowered.[34]
- Air Combat Command could find no historical record of the process used to establish most of the goals.[35]
- AMC compared the goals with the actual rates for the previous 2 years. Depending upon actual performance, the goal could then be changed, sometimes on the basis of subjective judgments.[36]

It is vitally important to examine the effectiveness and validity of metrics and their associated standards. Many hours are spent preparing for and participating in meetings discussing the performance of organizations, all of which is wasted if the metrics or standards are ineffective at measuring organizational performance and driving the desired behavior. Budgets and other requirements are driven in part from metrics. If the metrics being utilized are not valid, the effectiveness of the organization to meet warfighter needs is also difficult to accurately measure.

Air Force maintenance metrics are presented with an associated numerical standard or goal[37] and managers are required to account for failure to meet those standards. These failures are reported at unit, command, and Air Force levels, but what if the established standard is inaccurate, unrealistic, or unattainable? Consider Table 3, which identifies historical MC performances for the C-5 at various points in time compared with the assumption used in establishing the C-5 MC standard.

During Operations Desert Shield and Desert Storm in FY91, the MC rate was less than 71 percent. During Operation Iraqi Freedom in FY03, the MC rate was less than 64 percent. This is particularly intriguing because numerous personnel interviewed during the original research suggested MC rates have been or should be usually better during conflicts.[39] Indeed, the highest quarterly MC rate the C-5 total fleet achieved, 81.8 percent, was observed during first quarter of FY91 (during Operation Desert Shield). Considering the data points in Table 3 are rates achieved during wartime scenarios, the feasibility of using 75 percent as the day to day, peacetime C-5 MC standard appears questionable at best.

Still, consistent failures to meet a standard can often be perceived as a shortfall in the performance of the units supporting the C-5, rather than an unrealistic expectation not being met. Again, a tremendous amount of time and effort is put forth explaining why standards are not met. Historical C-5 MC rate performance would suggest that the standard and its associated metric are not driving improvement in performance, which is the fundamental purpose of a performance measure. A metric and its associated standard should drive performance, not simply document it, and the measure should be useful for decisionmaking. Additionally, the *Air Force Smart Operations for the 21st Century Concept of Operations (CONOPS)* identifies good process metrics as having the following attributes:[40]

- Accurate – reliably expresses the phenomenon being measured
- Objective – not subject to dispute
- Comprehensible – readily communicated and understood
- Easy – inexpensive and convenient to compute
- Timely – data sources are available
- Robust – resistant to being gamed and hard to manipulate[41]

As previously stated, the current standards methodology involves differences across the total force. Additionally, the study team interviewed many subject matter experts while conducting site visits for this research. Some of them indicated the consistent inability to achieve an MC standard of 75 percent led to an attitude of frustration, indifference and apathy towards the standards.[42] AFI 21-101 states that "metrics shall be used at all levels of command to drive improved performance."[43] In the case of the C-5, the existing maintenance standards methodology associated with the MC and TNMCM metrics appear to cause those metrics to fall short of this goal.

Alternative Strategies to Performance Measurement

As described in the second article in this series, the AFLMA study team interviewed representatives from the Delta Airlines reliability programs office as a means of comparing business practices. Delta personnel identified nine main aircraft maintenance metrics. Of note was the fact that Delta's primary metrics (those driven by delays and cancellations) were not measured to an objective standard (met or not met); instead, they alert when they exceed a control limit for 2 consecutive months.[44]

Using control limits, found in control charts, is a commonly used technique for determining if a process is in a state of statistical control. First developed by Shewhart, many influential quality leaders have advocated the proper use of control charts, most notably W. Edwards Deming. Generally speaking, recent data is examined to determine the control limits that apply to future data with the intent being to ascertain whether the process is in a state of control.[45] Charts alone cannot induce process control; stabilization or improvement is the challenge of people in the process.[46] Viable control limits can only be developed for processes in a state of statistical control, and they are best applied to process variables rather than product variables.[47] For example, consider the manufacturing process of a metal component. The product variables might be thickness or diameter, whereas process variables could be temperature or pressure at the point of forging. The benefit of monitoring process variables better allows someone to assign cause to variation. Using the previous example, variance in component diameter indicates a problem but requires further investigation to determine the cause. However, excessive pressure measurements identify the cause behind improper component diameter. Essentially, process variable measurements identify causes that could affect product variables.[48]

Today, many maintenance units are using versions of control charts to monitor performance in terms of the various metrics listed in AFI 21-101.[49] For example, Figure 1 illustrates TNMCM performance (large solid black line), with upper and lower control limits (represented by the solid red lines), at Dover Air Force Base (AFB) during calendar year 2006. Although the effort to use control charts is a step in the right direction, there can be two major problems associated with the use of charts akin to those of Figure 1.

First, Air Force metric measurements such as TNMCM are not process variables; consequently, they do not lend themselves to the immediate, precise root-cause analysis that usually follows from control charts. This is evidenced by the copious explanatory notes pages accompanying products like the CSAF quarterly review slideshow.[51] In fact, the *C-5 TNMCM II* study team's analytical effort identified 184 factors that bear influence on the C-5 TNMCM rate. An additional confounding element is that status of aircraft and the categorization of hours (such as *possessed*) bear direct influence on the outcome of rates such as TNMCM, and this process is not consistent. Study team discussions with maintenance personnel revealed that aircraft status is not an exact science, and status documentation can be vulnerable to manipulation for the sake of improving numbers. For example, this can happen by delaying aircraft status changes

	MC Rate	Time Period
AMC C-5 MC Standard	75%	~1990 – Present[38]
Operation Desert Shield/Desert Storm	70.6%	Fiscal Year 1991
Operation Iraqi Freedom	63.4%	Fiscal Year 2003
Highest Quarterly MC Rate Achieved	81.8%	Fiscal Year 1991, Quarter 1

Table 3. C-5 Fleet Historically Achieved MC Rates[38]

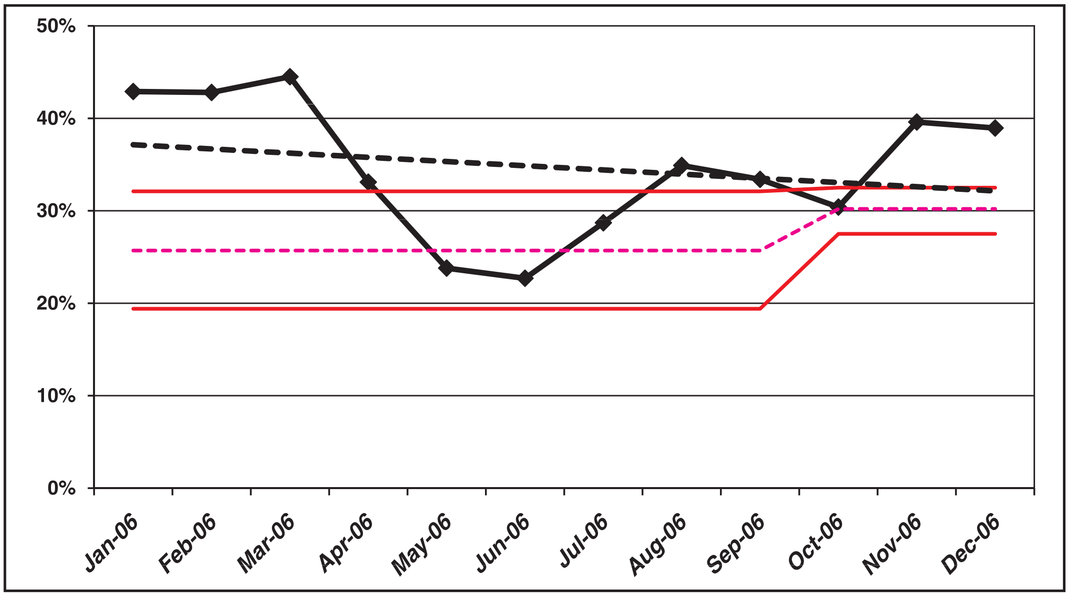


Figure 1. Example of TNMCM Control Chart, Dover AFB 2006[50]

by not changing the status to NMCM or NMCS as soon as an aircraft breaks and maintenance is underway or work stoppage occurs due to needed parts.

The categorization of hours is something that is in stark contrast with the host of metrics used by Delta Airlines, which upon examination appeared more tangible, more easily measured, and less easily manipulated. Again, a thorough discussion of Delta's maintenance metrics was included in a previous article in this book.

Next, upon examination of the control chart in Figure 1, one sees that the centerline mean (small dashed line between the solid red lines) is set at 30.2 for the months in FY07, with the upper and lower control limits set at 32.5 and 27.5, respectively.[52] The study team sought to uncover the specific methodology used to arrive at the centerline mean, as well as the upper and lower control limits. Personnel at Dover stated that the control limits are downward directed from headquarters AMC. The managing office at AMC stated that the control limits were derived from 2 years of historical data for all of AMC, with a range of one standard deviation above and below the mean.[53] There are two issues with this approach. First, the figure is not arrived at through subgroup sampling of at least 20 subgroups, as advocated by statistical analysis literature.[54] Secondly, this centerline mean is known as the *AMC goal* for the TNMCM rate. Interestingly, it is higher (that is, less ambitious) than the active duty TNMCM standard, which was 24 for the FY07 timeframe. The fact that AMC units are using a different figure than the established active duty standard for management purposes is further evidence that fleet standards appear to have limited influence on performance at base levels.

However, as noted in the 2005 AMC Metrics Handbook, because AMC command goals are rooted in wartime operational requirements, there are some standards that are difficult or impossible to achieve during peacetime operations.

> Using the *command average* is one way around this shortcoming. Comparing (your base) to command averages helps to gauge true performance and is invaluable for identifying if a problem is local or fleet wide. AMC weapons system managers (WSMs) use command averages for understanding overall performance of their fleets. When discussing performance problems with AMC WSMs, base personnel should have a good understanding of where their base performance numbers are in relation to the command average.[55]

It should be noted that the study team was not advocating the use of the active duty standard as the centerline mean for this control chart. In fact, extreme caution must be taken when using a standard value as opposed to the sampling mean as the centerline for performance. Although the intent might be to control the process mean at a particular value, one runs the risk that the current process is incapable of meeting that standard. For example, if the lower and upper control limits are calculated from the standard, and the current process mean exceeds the standard, subgroup averages might often exceed the upper limit, even though the process is in control. This lessens the ability to determine assignable causes of variation, because the only observation is that the process isn't conforming to the desired value.[56] This may, in fact, be what was actually occurring with the MC metrics for the C-5 fleet.

What Should the TNMCM Standard Be?

If the existing standard's equations were used with current C-5 aircraft data (rather than using the 75 percent MC input from AMC for the active duty fleet) to calculate the active duty fleet MC, TNMCS, and TNMCM standards, the resulting standards[57] would be:

- MC Standard = 56.8
- TNMCS Standard = 20.6
- TNMCM Standard = 29.3

These figures are presented for informational purposes only in order to illustrate the stark contrast with the active duty standards in place at the time of the original report's publication (MC = 75, TNMCS = 8, and TNMCM = 24). The study team was not advocating the use of the standards presented above. Instead, the examination presented here and in the study report led to the recommendation that AMC and Air Staff develop a repeatable methodology to compute a standard focused on three things. These three things are listed in the recommendations section of this article. Such a methodology would better align to the original charter from the 2003 CORONA, which was to develop Air Force standards rooted in operational requirements and resources dedicated to the weapon system or MDS.

Conclusions

The process for calculating and establishing Air Force-level TNMCM standards is not well known across the Air Force and not equally applied across the total force. Also, the process currently in use does not produce realistic, capability-based metrics to drive supportable operational decisions.

Recommendations

Develop a repeatable methodology to compute the standard that:

- Reflects day-to-day minimum operational requirements
- Adjusts to fully mobilized force capabilities and surge mobility requirements
- Accounts for historic capabilities and fleet resources

As previously mentioned, the analysis of maintenance metric standards described in this article was developed as part of the larger *C-5 TNMCM Study II*. This is the third and final article in a series related to that particular research. The entire study report can be found at the Defense Technical Information Center private Scientific and Technical Information Network Website at https://dtic-stinet.dtic.mil/.

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Decisive means and results are always to be preferred, even if they are not always possible. We should always be skeptical when so-called experts suggest that all a particular crisis calls for is a little surgical bombing or a limited attack.… History has not been kind to this approach to warmaking.

—Gen Colin L. Powell, USA

As soon as they tell me it is limited, it means they do not care whether you achieve a result or not. As soon as they tell me it's surgical, I head for the bunker.

—Gen Colin L. Powell, USA

About the Authors

Major Scotty A. Pendley *is currently the Operations Officer, Maintenance Branch, Logistics Innovation Studies Division, Air Force Logistics Management Agency. He is a career aircraft maintainer and holds a master of science degree in logistics management from the Air Force Institute of Technology.*

Benjamin A. Thoele *is currently employed as the Executive Director of the FitWit Foundation in Atlanta, Georgia. He previously worked as a Captain in the Air Force Logistics Management Agency as an operations researcher and Chief, Logistics Analysis. He holds a master of science degree in operations research from the Air Force Institute of Technology.*

Jeremy A. Howe *is currently employed with the Whirlpool Corporation, Corporate Headquarters as the Manager, North American Region Supply Chain Metrics Team. He previously worked as a Captain in the Air Force Logistics Management Agency as Chief, Munitions Analysis. He holds a master of science degree in logistics management from the Air Force Institute of Technology.*

Major Anthony F. Antoline *is currently the Chief, Maintenance Studies Branch, Air Force Logistics Management Agency. He is a career aircraft maintainer and educator and holds a master of science degree in workforce education and development from Southern Illinois University and a doctorate in workforce education and development from Southern Illinois University.*

Roger D. Golden *is the Director, Air Force Logistics Management Agency. He holds a master of science degree in administration (management) from Georgia College, a master of science degree in strategic studies from the Air War College, and a doctorate in public administration from the University of Alabama.*

Major Timothy W. Albrecht *is currently the Chief, Operational Assessments, AFCENT/A3XL Long Range Plans, Shaw AFB, South Carolina. He was previously the Chief Scientist at the Air Force Logistics Management Agency. He holds a master of science and doctorate degrees in operations research from the Air Force Institute of Technology.*


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